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TECHNICAL REPORT NO. 3-783

AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE

APPENDIX B: VEHICLE PERFORMANCE IN LATERAL AND LONGITUDINAL OBSTACLES (VEGETATION)

VOLUME I: LATERAL OBSTACLES

by

C. A. Blackmon
J. K. Stoll

December 1968

Sponsored by

Advanced Research Projects Agency

and

Directorate of Development and Engineering
U. S. Army Materiel Command

Service Agency
U. S. Army Materiel Command

Projects Nos. 1-V-0-25001-A-131 and 1-V-0-21701-046-02

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA), and is a portion of one task of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command (AMC) was the service agent. The broad mission of Project MERS was to determine the effects of the various features of the physical environment on the performance of cross-country ground contact vehicles and to provide therefrom data that can be used to improve both the design and employment of such vehicles. A condition of the project was that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. Some funds for preparation and publication of this report were provided by the Directorate of Development and Engineering, AMC, under Department of the Army Project 1T062109A131, "Military Evaluation of Geographic Areas," and Task-02 "Surface Mobility," of Project 1T062103A046, "Trafficability and Mobility Research." The field work was performed during the period June 1964 to November 1965, under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This appendix is one of seven to the report entitled An Analytical Model for Predicting Cross-Country Vehicle Performance. These appendixes are:

A. Instrumentation of Test Vehicles

FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA), and is a portion of one task of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command (AMC) was the service agent. The broad mission of Project MERS was to determine the effects of the various features of the physical environment on the performance of cross-country ground contact vehicles and to provide therefrom data that can be used to improve both the design and employment of such vehicles. A condition of the project was that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. Some funds for preparation and publication of this report were provided by the Directorate of Development and Engineering, AMC, under Department of the Army Project 1T062109A131, "Military Evaluation of Geographic Areas," and Task-02 "Surface Mobility," of Project 1T062103A046, "Trafficability and Mobility Research." The field work was performed during the period June 1964 to November 1965, under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This appendix is one of seven to the report entitled An Analytical Model for Predicting Cross-Country Vehicle Performance. These appendixes are:

A. Instrumentation of Test Vehicles

B. Vehicle Performance in Lateral and Longitudinal Obstacles (Vegetation)

Volume I: Lateral Obstacles

Volume II: Longitudinal Obstacles

C. Vehicle Performance in Vertical Obstacles (Surface Geometry)

D. Performance of Amphibious Vehicles in the Water-Land Interface (Hydrologic Geometry)

E. Quantification of the Screening Effects of Vegetation on Driver's Vision and Vehicle Speed

F. Soil-Vehicle Relations on Soft Clay Soils (Surface Composition)

G. Application of Analytical Model to United States and Thailand Terrains

The study was conducted by personnel of the Area Evaluation Branch, Mobility and Environmental (M&E) Division, under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley, Chief, M&E Division; Mr. S. J. Knight, Assistant Chief, M&E Division; Mr. A. A. Rula, Chief, MERS Branch; Mr. Warren E. Grabau, Chief, Area Evaluation Branch; and Mr. Jack K. Stoll, Chief, Field Test Section, who was in direct charge of all phases of the study. Personnel of WES technical support elements provided major assistance in the field test program. Analysis of the data was performed by Mr. C. A. Blackmon. This report was written by Messrs. Blackmon and Stoll.

Directors of the WES during this study and preparation of this report were COL Alex G. Sutton, Jr., CE; COL John R. Oswalt, Jr., CE; and COL Levi A. Brown, CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

NOTATION

A	Area of structural cell, ft^2
$\overline{A}$	Mean area per stem, ft^2
A_d	Area denied, ft^2
C	Cohesion, psi
d_a	Diameter of mean area per stem, ft
d_o	Diameter of circle whose area is equivalent to the area occupied by an obstacle, in.
d_s	Diameter of stem, in.
D_c	Diameter of structural cell, ft
D_p	Actual path length of test run, ft
D_s	Straight-line distance from beginning to end of test run, ft
L_m	Length of major axis of elongated obstacle, ft
s_e	Mean obstacle spacing, ft
t	Total time of test, sec
w	Width of vehicle, ft
ϕ	Friction angle, deg
Ω	Angle at which vehicle approaches elongated obstacle, deg

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square feet	0.092903	square meters
miles	1.609344	kilometers
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
miles per hour	1.609344	kilometers per hour
pounds per cubic foot	16.0185	kilograms per cubic meter
short tons (2000 lb)	907.185	kilograms

SUMMARY

A total of 95 lateral obstacle tests were conducted with two tracked and three wheeled vehicles at the NASA Marshall Space Flight Center, Miss., and Eglin Air Force Base, Fla. The principal conclusions from these tests were that (a) vehicle performance in terms of speed made good in an array of vegetation assemblages can be correlated with the density of vegetation assemblages expressed as mean obstacle spacing, (b) the minimum obstacle spacing required to permit movement of a vehicle can be computed from vehicle width, and (c) the speed made good a vehicle can achieve when maneuvering in lateral obstacles is significantly affected by the slope of the terrain.

Methods of determining mean obstacle spacing from structural cell diameter and percent area denied from stem diameters of trees, vehicle width, and structural cell diameter are shown. A method of determining percent area denied by logs, mounds, and other obstacles is suggested.

AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE

APPENDIX B: VEHICLE PERFORMANCE IN LATERAL AND LONGITUDINAL OBSTACLES (VEGETATION)

VOLUME I: LATERAL OBSTACLES

PART I: INTRODUCTION

Background

1. The main text of this report describes the development of an analytical model for predicting the cross-country performance of a vehicle. The model was based on an energy concept within the framework of classical mechanics that requires cause-and-effect relations be established between discrete terrain factors and vehicle response. This volume of Appendix B deals with the effects of a single terrain factor--lateral obstacles. The term "obstacles" in general refers to all features of the terrain, except soil, that are inhibitory to vehicle mobility. The obstacle-effects spectrum on vehicle mobility ranges from complete immobilization to minor speed reduction. For the purpose of the overall study, obstacles were categorized according to the direction of motion forced upon a vehicle negotiating the obstacle, i.e. vertical, lateral, or longitudinal.

2. The lateral obstacle category includes trees, boulders, holes, mounds, etc., that the vehicle cannot or does not, through the operator's choice, override.

Purpose and Scope

3. This volume describes the lateral obstacle tests conducted during the period August 1964-April 1965. The general purpose of these tests was to obtain data relating characteristics of lateral obstacles to vehicle performance in terms suitable for use in developing that portion of the analytical model for cross-country performance. The specific purposes were to determine (a) if vehicle performance, in terms of speed made good, could

be related to the mean spacing of trees as defined by the structural cell,* and (b) what other characteristics of vegetation and what vehicle characteristics are suitable for the development of empirical performance relations.

4. Ninety-five tests were conducted with five vehicles in fairly homogeneous forests at eight sites in two general areas. The diameters of the trees ranged from about 4 to 10 in.** The lowest branches of the trees were sufficiently high so as not to impede the vehicles. The sizes and distribution of the trees at each site were determined, and the time required for each traverse (traverses ranged from less than 100 to about 900 ft) was recorded.

5. Although only vegetation was tested, the application of the principles and analysis techniques to other types of lateral obstacles is discussed in this report.

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* The structural cell concept with its derivatives, mean tree spacing, nearest neighbor distance, etc., has been explored with some intensity by the U. S. Army Engineer Waterways Experiment Station. The concept is described in "Quantitative Physiognomic Analysis of the Vegetation of the Florida Everglades," by H. L. Mills, Contract Report No. 3-72, 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.; prepared by Marshall University, Huntington, W. Va.

** A table of factors for converting British units of measurement to metric units is presented on page xi.

PART II: TEST PROGRAMS

Location and Description of Test Areas

6. The tests reported herein were conducted at two locations in the southeastern United States: NASA Marshall Space Flight Center, near Picayune, Miss., and Eglin Air Force Base (EAFB), Fla. (fig. B1). Descriptions of test sites at the time the tests were conducted are given in the following paragraphs.

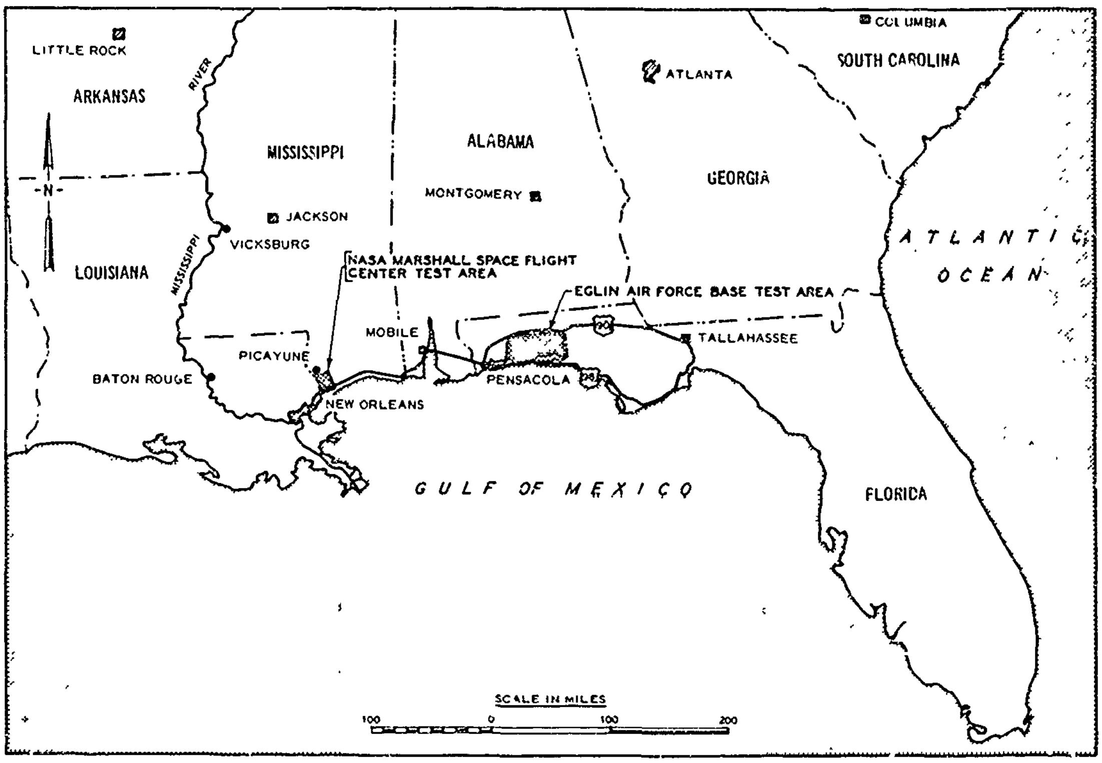


Fig. B1. Vicinity map, NASA Marshall Space Flight Center and Eglin Air Force Base test areas

NASA Marshall Space Flight Center

7. The four sites at NASA Marshall Space Flight Center were identified as NASA1, NASA2, NASA3, and NASA4 (fig. B2). The sites were approximately 500 ft long and 250 ft wide and very nearly level (less than 0.5 percent slope along each test run). Trees at the sites were coniferous, or coniferous and hardwood mixed. Ground cover varied from pine straw to small bushes (fig. B3). Soils in the area were classified as ML, CL-ML,

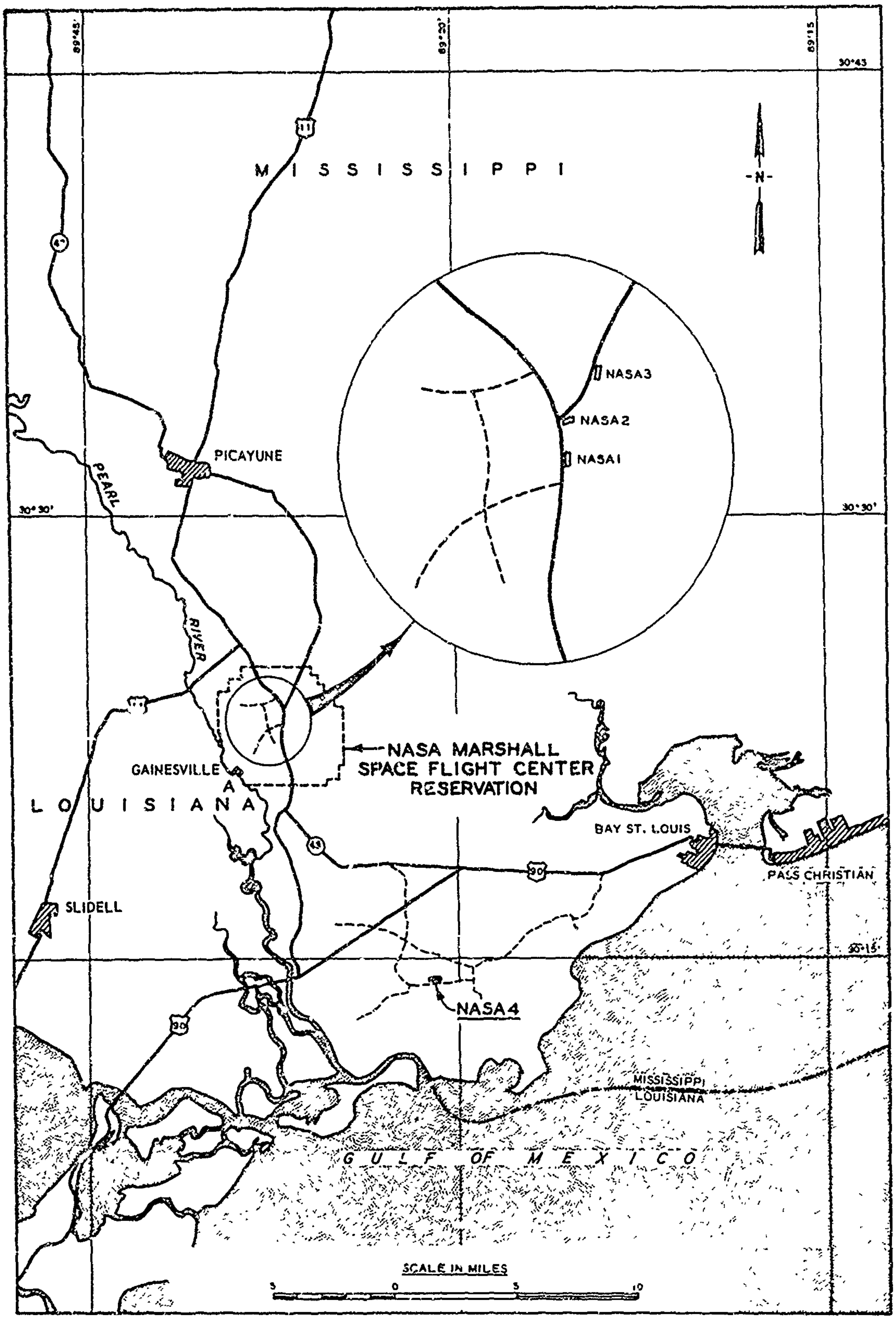
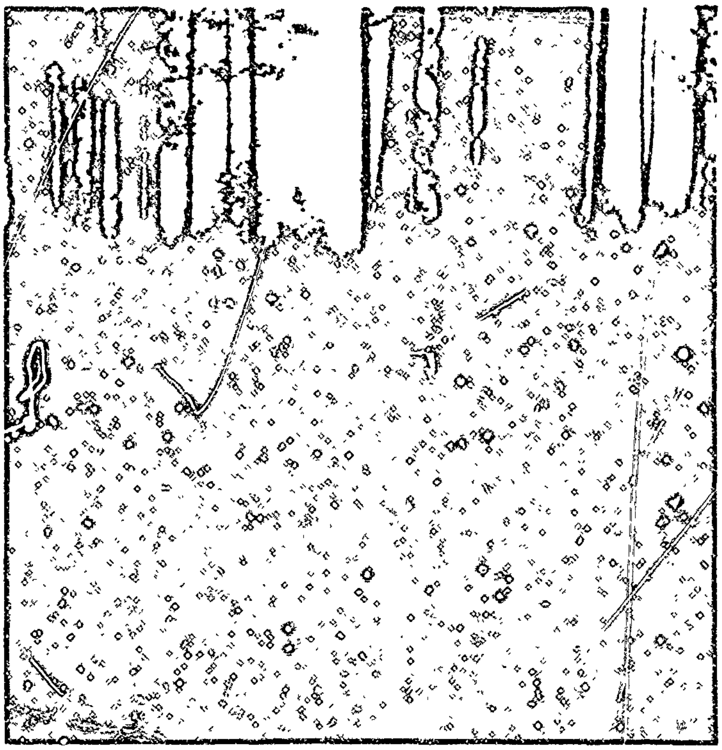
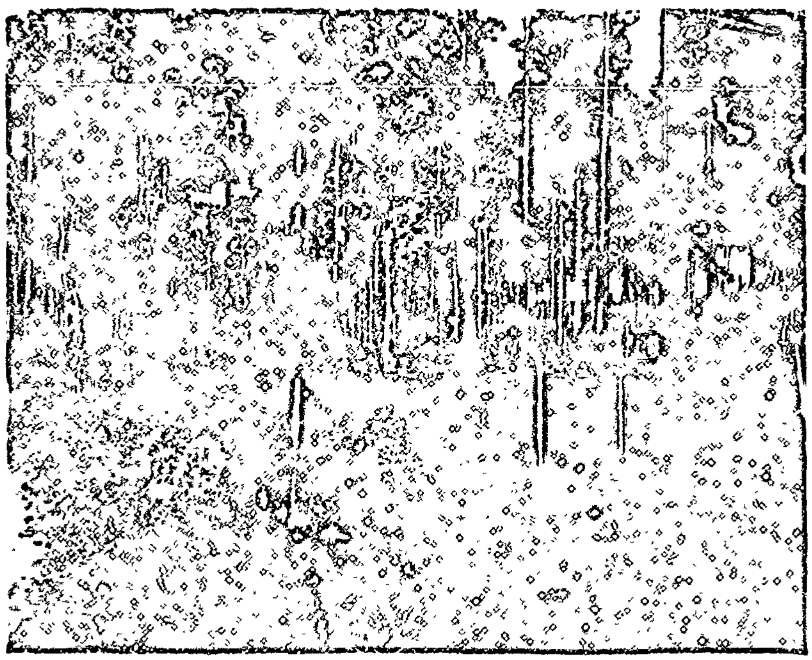


Fig. B2. Location of test sites, NASA Marshall Space Flight Center test area



a. Pine-straw-covered surface



b. Brush-covered surface

Fig. B3. Surface covers at NASA Marshall Space Flight Center test area

and SM, according to the Unified Soil Classification System (USCS). Average cone index in the 0- to 6-in. layer ranged from 55 to 316 and in the 6- to 12-in. layer from 67 to 375. A few stumps and stump holes were scattered over the area, and these were marked with stakes and considered as lateral obstacles.

Eglin Air Force Base

8. The four sites at Eglin were identified as E1, E2, E3, and E4 (fig. B4). Each site was approximately 500 ft long and 250 ft wide. The ground surface was sloping at all sites in the EAFB area; slopes ranged from 0.5 to 12.6 percent (fig. B5). Trees at the sites were coniferous, or coniferous and hardwood mixed (fig. B6). Small trees and all large bushes were cleared from the sites leaving a surface cover of pine straw and small brush. Soils in the EAFB area were classified as SP according to the USCS. Average cone index in the 0- to 6-in. layer ranged from 54 to 172, in the 6- to 12-in. layer from 70 to 351. The few stumps and stump holes scattered over the area were marked with stakes and considered as lateral obstacles.

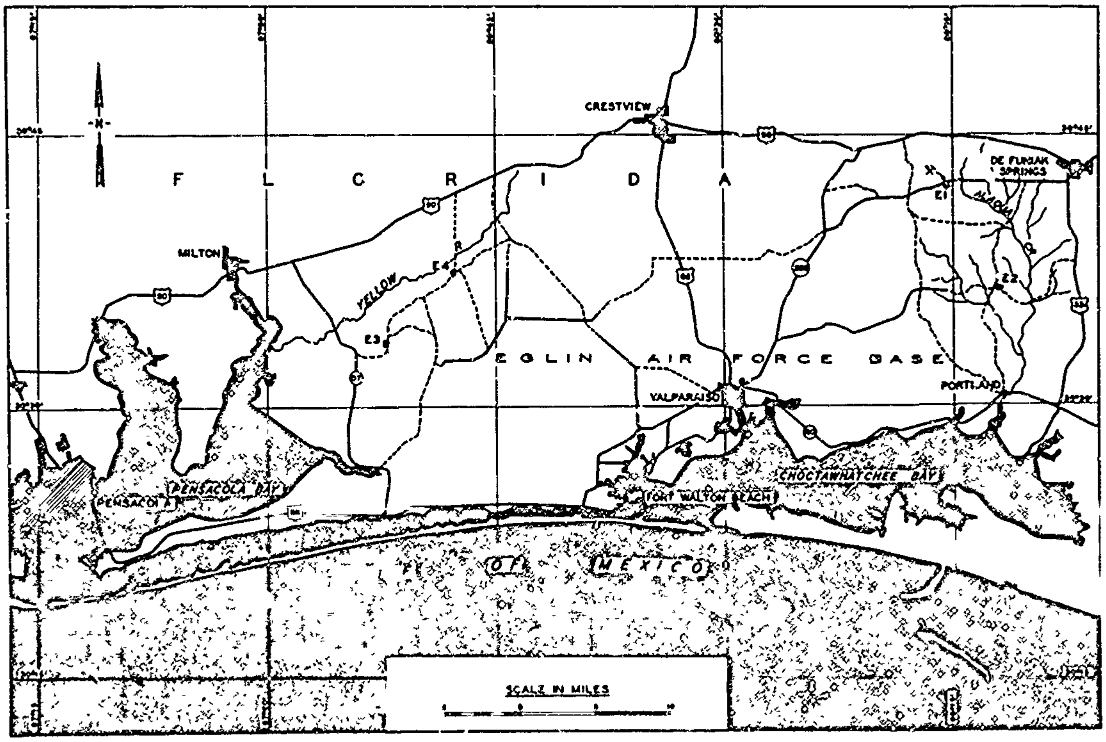
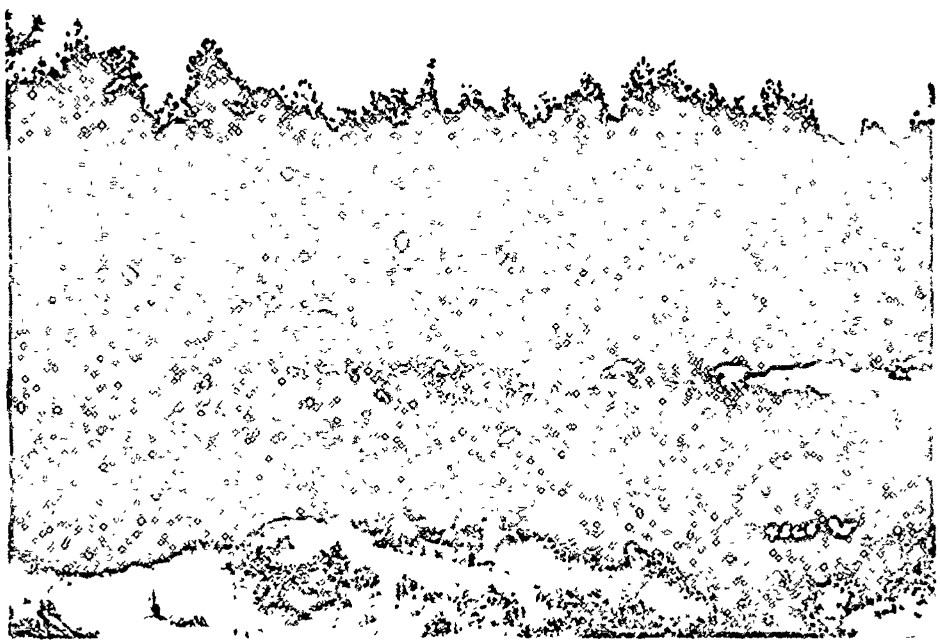


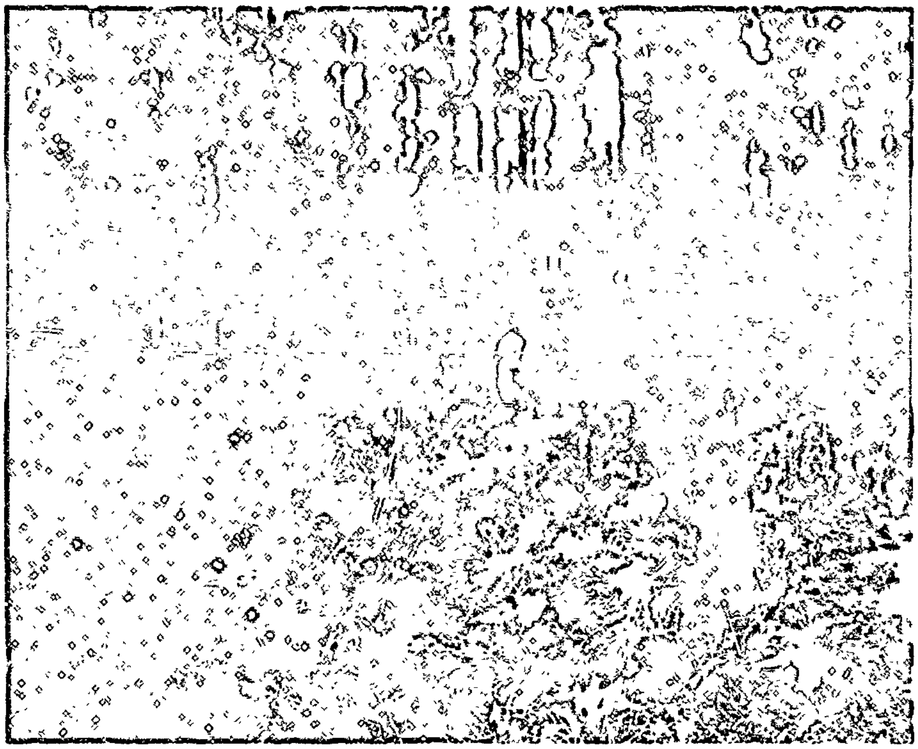
Fig. B4. Location of test sites, Eglin Air Force Base test area

a. Gentle slopes

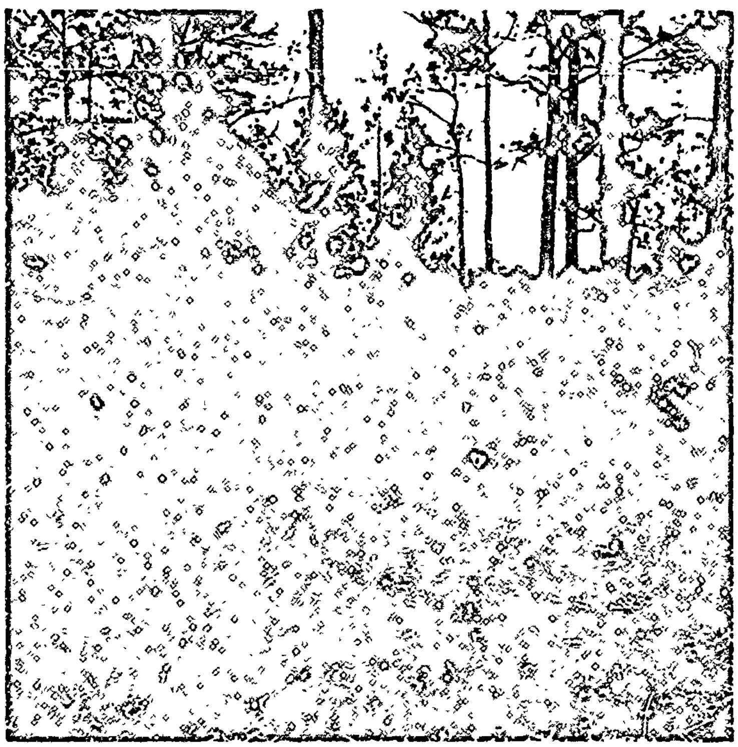


b. Steeper slopes

Fig. B5. Ground surface slopes at EAFB test area



a. Coniferous trees

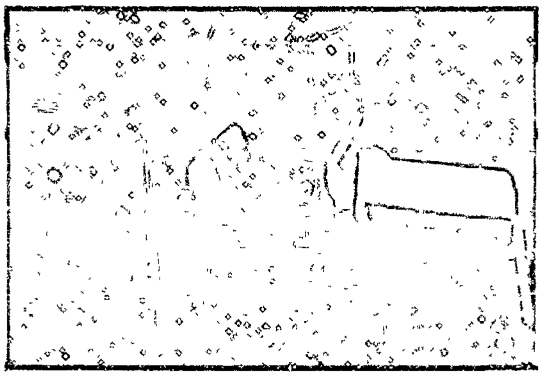


b. Coniferous and hardwood trees

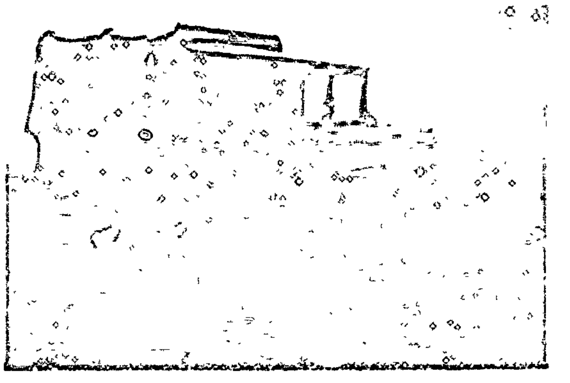
Fig. B6. Trees at EAFB test area

Vehicles Used

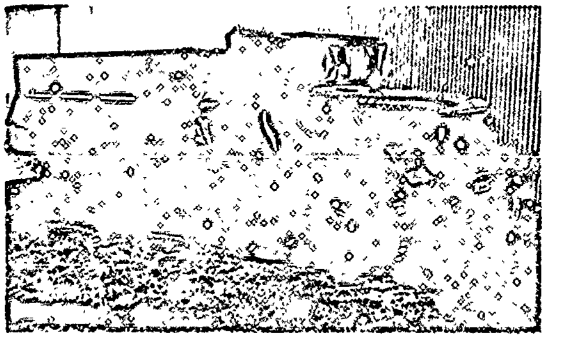
9. Three wheeled vehicles--the M151 1/4-ton utility truck, the M37 3/4-ton cargo truck, and the M35A1 2-1/2-ton cargo truck--and two tracked vehicles--the M29C amphibious cargo carrier and the M113 armored personnel carrier--were used in these tests (see figs. B7 and B8). Pertinent



a. M151 1/4-ton utility truck

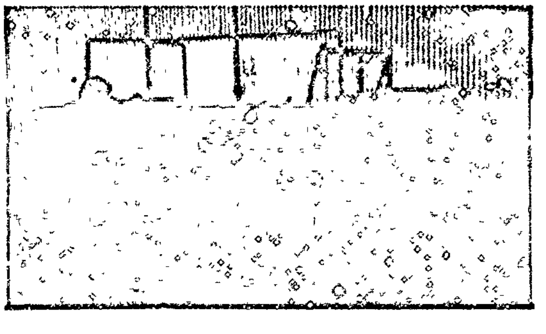


b. M37 3/4-ton cargo truck

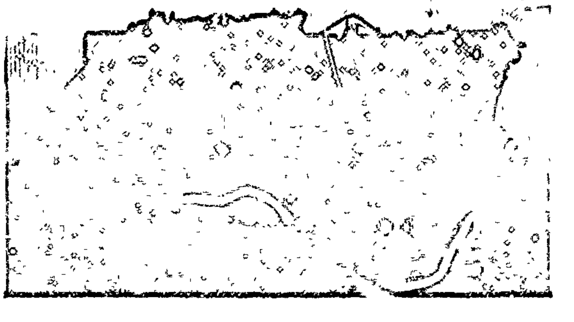


c. M35A1 2-1/2-ton cargo truck

Fig. B7. Wheeled vehicles used in test program



a. M29C amphibious cargo carrier



b. M113 armored personnel carrier

Fig. B8. Tracked vehicles used in test program

physical characteristics of the vehicles are given in table B1.

10. All of the vehicles, with the exception of the M151, were equipped with fairly elaborate measuring and recording systems.*

Tests Conducted

11. The tests sought answers to the questions "How fast can these vehicles go through a stand of trees?" and "To what physical characteristics of the vehicle and of the tree stand can this speed be related?" The testing approach was straightforward; tree stands of reasonably uniform density were located and the vehicles were maneuvered through them at the fastest speeds possible commensurate with the driver's ability. The mean structural cell diameter (an inverse index of tree density), the mean stem diameters, and the number of tests with each vehicle at each site were as follows:

Location	Mean Structural Cell Diam ft	Main Stem Diam in.	No. of Tests M151	M37	M35A1	M29C	M113	Total
NASA3	34	4.4	1	3	0	2	0	6
E2	48	8.1	2	2	0	4	0	8
E3	54	5.2	3	3	2	5	0	13
NASA2	62	8.6	2	2	2	3	4	13
E4	67	4.4	3	3	3	5	5	19
E1	70	6.2	4	3	4	3	4	18
NASA4	77	9.8	0	2	0	2	2	6
NASA1	132	6.5	2	2	2	2	4	12
		Total	17	20	13	26	19	95

* These systems are described in detail in "An Analytical Model for Predicting Cross-Country Vehicle Performance; Appendix A: Instrumentation of Test Vehicles," by B. O. Benn and M. Keown, Technical Report No. 3-783, July 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

12. Aproach lanes permitted the driver to enter the test site at the desired speed. He continued through the site in the most expeditious manner while avoiding all of the trees. A separate point of entry was selected for each test within a given site so that tests would be over different paths. Only one driver was used in the test program.

13. Instrumentation installed on the test vehicles (except the M151 1/4-ton truck) recorded continuous measurements of time, drive shaft revolutions, wheel or track rotational velocity, and drive line torque. In addition, for some tests vertical and longitudinal accelerations were measured and recorded. Event marks on an oscillogram indicated the beginning and end of the test and correlated the record with ground reference points. An example of an oscillogram record is shown in fig. B9. For the M151 1/4-ton truck, time from start to end of the test

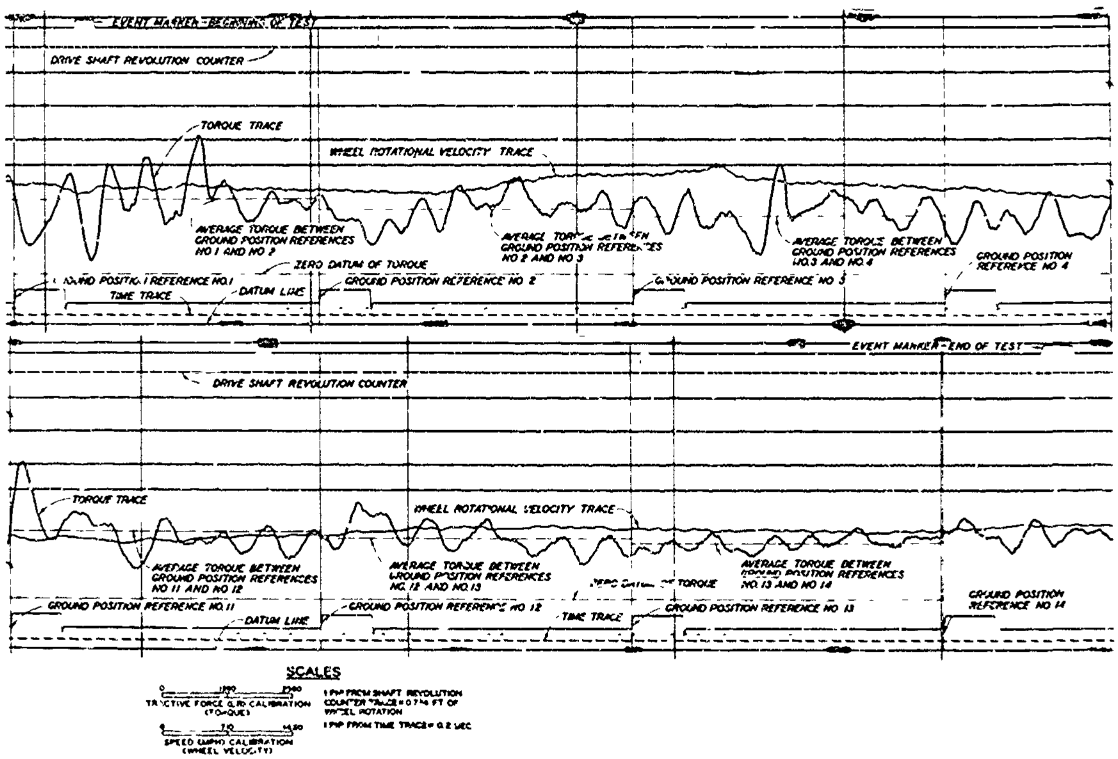


Fig. B9. Oscillogram record, test 281, M37 3/4-ton cargo truck

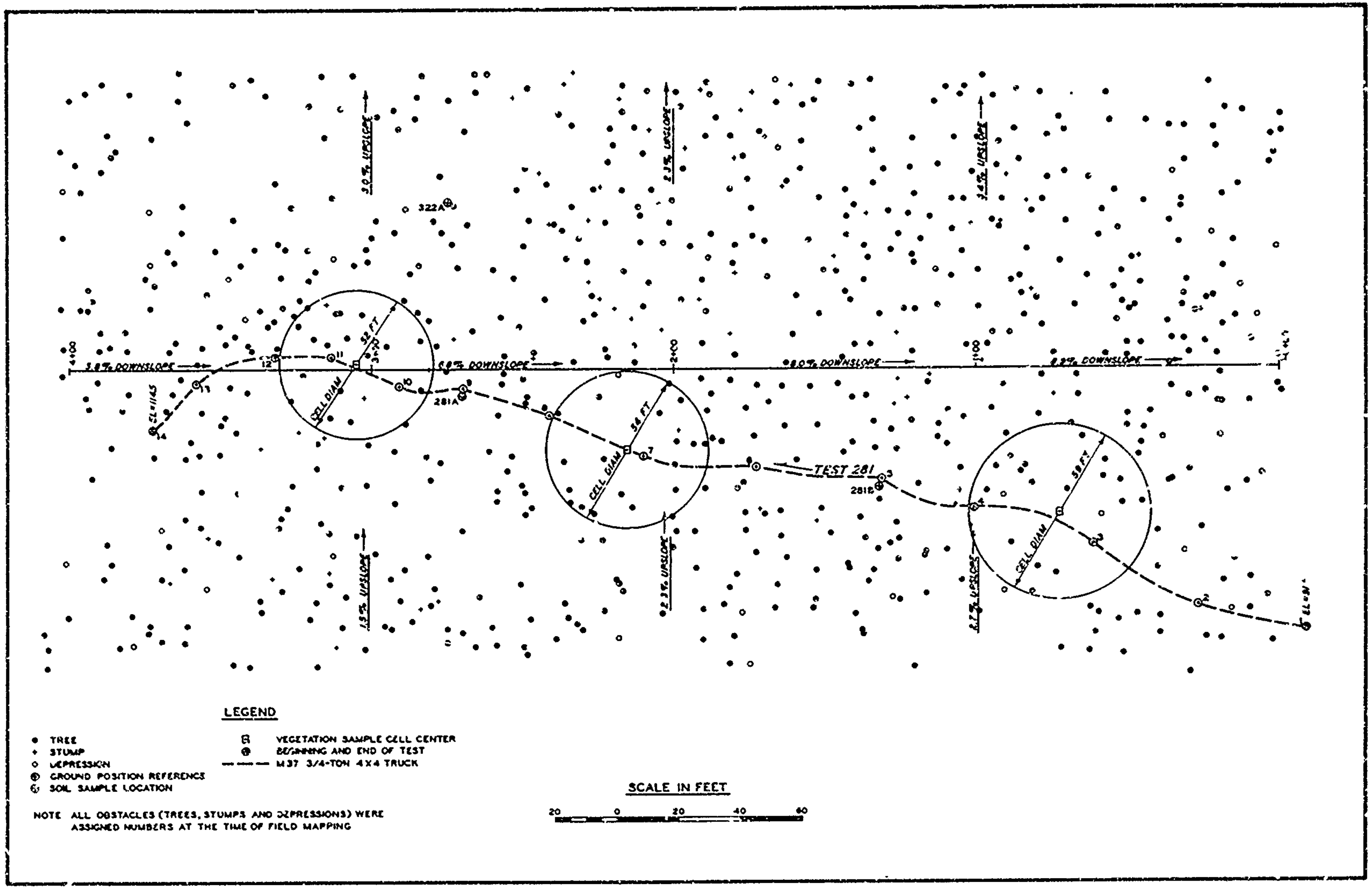


Fig. B10. Planimetric map of lateral obstacles, test site E2

run was measured by a stopwatch. A stopwatch was also utilized on the other vehicle tests in case the oscillograph recorder malfunctioned and to permit a quick estimate of speed immediately after each test. Appropriate data from the tests are summarized in table B2.

The Planimetric Map

14. To portray the tests graphically and for convenience in analysis of test results, a planimetric map was prepared of each test site, showing the location of each tree and other obstacles in the test site and the average slope perpendicular and parallel to the center line of the site. Following each test, the path of the vehicle was plotted on the map using a plane table and alidade in the field. The relative elevation of the ground was determined for the beginning and ending points of the test and all ground reference points along the path. The actual distance traveled by the vehicle and the straight-line distance from beginning to end of the test were measured on the planimetric map. At least three vegetation structural cells were constructed on the map along the path of the vehicle. An example of a planimetric map and structural cells is shown in fig. B10. Table B2 includes data obtained from the planimetric maps.

Soil Data Obtained

15. Generally two soil sampling locations were selected along the path of each test. A summary of the data obtained in the sampling is given in table B2.

Cone index

16. Ten cone index profiles were measured at each soil sampling location. Measurements were made at the surface and at 3-in. vertical increments to a depth of 18 in.

Rating cone index

17. Occasional remolding index measurements, which indicate the direction and magnitude of the change in strength of soil that will obtain under repetitive traffic, were made for the 0- to 6-in. and 6- to 12-in.

soil layers. The average cone index for a given soil layer was multiplied by the remolding index for that layer to obtain the rating cone index.

Surface shear measurements

18. Cohesion and frictional angle measurements were obtained with the Cohron sheargraph* for rubber-to-litter, rubber-to-soil, and soil-to-soil conditions at most soil sample locations.

Moisture content

19. Average moisture content was usually determined from the 0- to 1-in., 0- to 6-in., and 6- to 12-in. soil layers.

Density

20. Samples for the determination of unit dry weight were secured at most locations for the 0- to 6-in. and 6- to 12-in. soil layers.

Bulk samples

21. Samples for classification of the soil according to the USCS were obtained from the 0- to 6-in. and 6- to 12-in. layers for each test.

Other Data Obtained

22. Other data obtained included the following: stem diameter at breast height, crown diameter, tree height, branching height, tree common name, photographs, and notes and observations.

* "Operation Manual for the Cohron Sheargraph," July 1963, Wilson, Nuttall, Raimond, Engineers, Inc., Chestertown, Md.

PART III: ANALYSIS OF DATA

23. The data collected in this test program are analyzed below under three headings: Speed-Spacing Relations; Speed-Area Denied Relations; Notes, Observations, and Other Data Considered. The conditions and assumptions upon which the analysis is based are described briefly in the following section.

Basis of Analysis

24. The nautical term "speed made good" was selected as the parameter to represent the vehicle performance in this study. Speed made good is defined as the straight-line distance from the beginning to the end of the test run divided by the time required for the vehicle to make the run. The increase in distance traveled as a result of maneuvering during the tests is expressed in terms of a path elongation ratio, i.e. the actual path length divided by the straight-line distance.

25. From a study of the results of the tests reported herein and the findings in other programs it was determined that the size of the structural cell was the characteristic that best described a vegetation assemblage and that would serve as a starting point from which to derive parameters that could be empirically correlated with vehicle performance. Two such parameters are considered in this report. The first is mean obstacle spacing and is nonvehicle dependent; the second is area denied and is both obstacle and vehicle dependent. For the latter vehicle width was selected as the most significant vehicle characteristic. The development of each of the parameters is discussed in the appropriate section.

26. For the analysis the tests were separated into two groups on the basis of USCS soil type. The two groups were (a) fine-grained soils and sands with fines, poorly drained (ML, CL-ML, and SM) and (b) coarse-grained soils (SP). The range of soil strength encountered by each vehicle in each soil group is shown in the following tabulation.

Vehicle	Range of Average Cone Index of ML, CL-ML, and SM Soils		Range of Average Cone Index of SP Soils	
	0- to 6-in. Layer	6- to 12-in. Layer	0- to 6-in. Layer	6- to 12-in. Layer
M151	55-163	67-204	57-115	72-143
M37	89-316	109-375	57-115	72-143
M35A1	65-111	68-96	54-172	76-351
M29C	67-229	96-285	64-167	82-224
M113	59-182	81-207	55-63	70-129

From the tabulation above it can be seen that tests were run on a wide range of soil strengths in each soil group. Despite this, there were not enough tests at a uniform spacing and a range of soil strengths to determine the influence of variation in soil strength. From discussions with the driver following each test, it appeared that generally he had been able to reach the speed he desired, that is, that he drove as fast as he thought safe. The observers agreed insofar as the tests in narrow obstacle spacings were concerned, but believed that the driver could have achieved a higher speed in the wider spacings had the soil been firmer. The data in table B2 indicate slip for some tests; and the effect of slip on the driver's confidence, resulting in his selection of a lower speed, might be easily hypothesized. In brief, it is believed that further testing is warranted to determine the degree of significance of soil strength on vehicle performance in lateral obstacles.

27. Other factors affecting vehicle performance in lateral obstacles are discussed in the section Notes, Observations, and Other Data Considered.

Speed-Spacing Relations

Mean obstacle spacing

28. Mean obstacle spacing may be considered as the first derivative of the structural cell. When the area of the structural cell is divided by the number* of stems in the cell the result is the average or mean area

* In the structural cell concept, 20 stems comprise each structural cell. Lateral obstacles such as boulders, holes, mounds, etc., as well as trees are included in the stem count.

occupied by one stem. Considering this area as a circle with the stem at the center, the radius is the distance that is free before entering the mean area of another stem. Since the mean area per stem is equal for all stems in the cell, it follows that the mean distance or spacing between stems is equal to the diameter of the circle encompassing the mean area per stem. This diameter has been termed mean obstacle spacing. It should be noted that mean obstacle spacing approximates the difference between tree centers. Two equations to calculate mean obstacle spacing are derived below.

Equation Based on Diameter	Equation Based on Area
$\bar{A} = \frac{A}{20}$	$\bar{A} = \frac{A}{20}$
$\frac{\pi d_a^2}{4} = \frac{\pi}{4}\frac{D_c^2}{20}$	$\frac{\pi d_a^2}{4} = \frac{A}{20}$
$d_a^2 = \frac{D_c^2}{20}$	$d_a^2 = \frac{4}{\pi}\frac{A}{20}$
$d_a = 0.224 D_c$	$d_a = 0.252\sqrt{A}$
and by definition	and by definition
$d_a = s_e$	$d_a = s_e$

where

A = area of structural cell = $\frac{\pi D_c^2}{4}$

$\bar{A}$ = mean area per stem = $\frac{\pi d_a^2}{4}$

D_c = diameter of structural cell

d_a = diameter of mean area per stem

s_e = mean obstacle spacing

Speed made good
versus mean obstacle spacing

29. Tests in fine-grained soils and sands with fines, poorly drained. Plots of speed made good versus mean obstacle spacing for tests conducted on nearly level surfaces of fine-grained soils and sands with fines, poorly drained, are shown in plate B1. The curves drawn through the data points represent lines of visual best fit. In fig. 1, plate B1, it can be seen that tests 242 and 243 had very nearly the same speed made good with a 2.5-ft difference in obstacle spacing. This was probably due to the selection of route by the driver. The actual speed for test 243 was 1.6 mph higher than that for test 242, but the path elongation ratio was 1.14 for test 243 and only 1.02 for test 242 and the speed made good reflected the longer route. The go or no go point on the ordinate in fig. 2, plate B1, is well established by tests 12 and 13B, which indicate spacings too small to permit passage of the M37, and test 13A, which represents a barely go condition. The data do not indicate why there was a 2.8-mph difference in speed made good for tests 263 and 264 in fig. 3 at approximately the same mean obstacle spacing. However, an average value for the two tests would be 14.4 mph and the deviation from this average is only ±10 percent. The location of the intercept of the curve in fig. 3, plate B1, with the abscissa was admittedly influenced by the tests on coarse-grained soils (paragraph 31). A comparison of the performances of the three wheeled vehicles is shown in fig. 4, plate B1. The curves indicate that the M151 performed best under the conditions tested. This was to be expected because of the size and maneuverability of the vehicle. The increase in the performance of the M35A1 over that of the M37 at higher mean obstacle spacing was probably due to the better acceleration of the M35A1.*

30. The intercept of the performance curve with the abscissa in fig. 5, plate B1, is defined by test 15A in which the vehicle was barely able to proceed. The slightly narrower spacing encountered during test 15B nearby was sufficient to prohibit passage of the vehicle. The curve shown

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* R. F. Depkin, "Wheeled Vehicle Performance Data Consolidation," June 1967, Aberdeen Proving Ground, Md.

in fig. 6, plate B1, was drawn without reference to test 29, a notable outlier. A careful review of the data from this test reveals no reason for the vehicle's poor showing in the indicated spacing. Barring this test, however, the scatter of the data in this figure, while somewhat more than might be desirable, does not appear excessive. The comparison of the performances of the M29C and the M113 in fig. 7, plate B1, indicates that the smaller vehicle, the M29C, was able to manuever through narrower spacings at a higher rate of speed made good than the M113 in the vegetation assemblages tested.

31. Tests in coarse-grained (SP) soils. Plots of speed made good versus mean obstacle spacing for tests conducted upslope and downslope in coarse-grained soils are shown in plate B2. A line that best separates upslope and downslope points is drawn on each plot. In figs. 1, 2, 5, and 6 of plate B2 the intercept of the line of separation with the abscissa was made to coincide with that shown in the corresponding figures in plate B1, while the intercept from the plot in fig. 3, plate B2 (the M35A1 tests), was transferred to the respective plot in plate B1. The line represents an approximation of the speed made good to be expected on level sandy soils.* Where the location of the line was doubtful, judgment was aided by the examination of the location and curvature of lines on better defined plots. Examination of the plots in plate B2 shows that the downslope tests tend to fall above and to the left of the separation line. The total number of plotted points for each set of data, the number that do not fall on the correct side of the separation line, and the percent falling on the proper side are given below. The last column in the tabulation below shows the percent of the total number of points that are on the correct side or the safe side. (An upslope speed greater than the line of separation indicates is considered to be on the safe side.)

* It is theoretically possible that the values of speed made good could be corrected for the effect of slope, but such an attempt is beyond the scope of this investigation.

Vehicle	Total Number of Points	Number Not Conforming	Percent Correct	Percent Correct or on the Safe Side
M151	12	1	92	92
M37	10	2	80	90
M35A1	9	1	89	89
M29C	17	2	88	100
M113	9	0	100	100

32. Note that only three points do not fall on the correct or safe side (tests 295, 266, and 291). When all tests are considered together the percent accuracy is 94.7, well above the acceptable limit for experimental error.

33. The summary curves for the wheeled vehicle tests in coarse-grained soils, fig. 4, plate B2, follow the same trend as those for fine-grained soils shown in plate B1; however, the speed at which the M35A1 begins to excel the M37 is somewhat lower. Again this may be the result of greater acceleration of the M35A1, and may also suggest that the influence of soil strength on speed in lateral obstacles varies with soil type. The summary curves for tracked vehicles are quite similar to those in plate B1, as would be expected.

Minimum obstacle spacing required

34. The mean obstacle spacing corresponding to a vehicle speed of 2 mph as indicated in plates B1 and B2 was considered to be the minimum obstacle spacing (min s_e) required for each of the vehicles tested. Attempts to relate this value to various vehicle characteristics revealed that the vehicle width yielded the best correlation. A plot of vehicle width (w) versus mean obstacle spacing is shown in plate B3. The line of best visual fit, extrapolated, passes through the origin. From this plot it can be seen that the minimum obstacle spacing required for the vehicles tested was 1.4 times the vehicle width.

35. It is obvious that the relation expressed in the paragraph above and in plate B3 will not hold true for all vehicles. Certainly vehicle length and turning radius can also affect the minimum obstacle spacing negotiable. Nor can it be assumed that this relation is valid for all

vegetation assemblages (since s_e ignores tree diameter, stilt or buttress roots, and branching habit). Nevertheless, for the range of vehicles tested and the conditions encountered, minimum obstacle spacing required can be determined from vehicle width (w) by the equation

$$\min s_e = 1.4w$$

Speed-Area Denied Relations

36. In an attempt to account for the effect of the diameters of the trees on speed made good (not considered in the mean obstacle spacing analysis) and to recognize the practical fact that a moving vehicle (especially a fast-moving one) cannot safely avail itself of every foot of space between two trees, the concept of "area denied" was evolved. Since it was clear from the analysis of the minimum mean spacing required by a vehicle (see plate B3) that the vehicle width was a significant parameter, it was felt that vehicle width should play a part in the concept.

37. Accordingly area denied (A_d) by a single tree was defined as the area encompassed by a circle whose diameter was equal to the stem diameter (d_s) plus the vehicle width (w). An example of the computation is shown in fig. B11. Note that although the area of the dashed circle

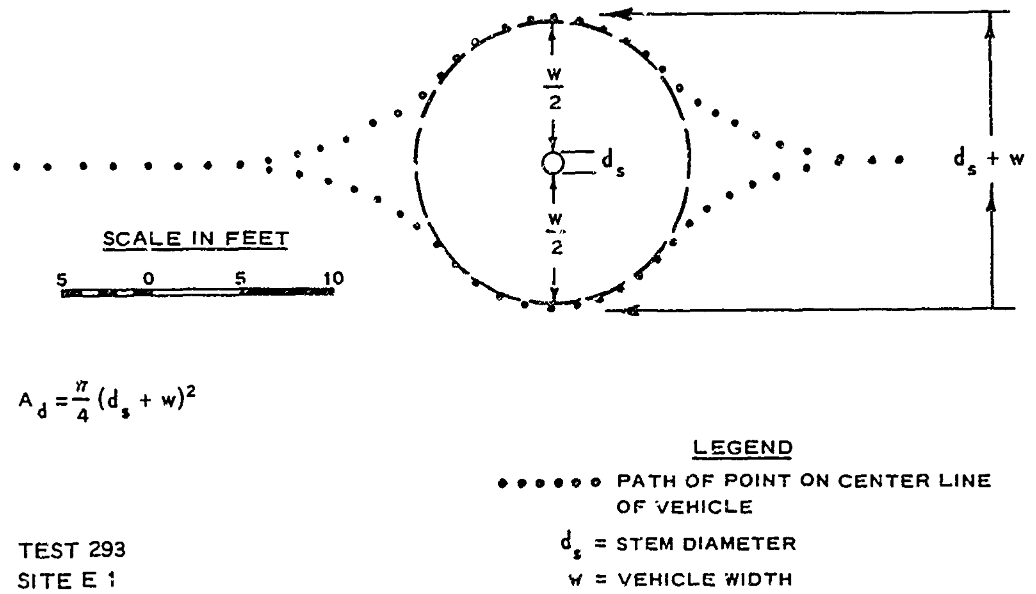


Fig. B11. Example of area denied by a single tree

is called "area denied" only that portion of the circle represented by the tree itself is truly denied to a (slow-moving) vehicle.

Percent area denied

38. The percent area denied equals the total area denied divided by the area of the structural cell, multiplied by 100. The equation for computing percent area denied ($\%A_d$) in a structural cell is

$$\%A_d = \frac{20(\bar{d}_s + w)^2}{D_c^2} \times 100$$

An example of the computation for test 293 is given below.

$$\bar{d}_s = 6.2 \text{ in.}; \; w = 8.0 \text{ ft}; \; D_c = 58 \text{ ft}$$

$$\%A_d = \frac{20\left(\frac{6.2}{12} + 8.0\right)^2}{(58)^2} \times 100$$

$$\%A_d = 0.429 \times 100$$

$$\%A_d = 43$$

Percent area denied
versus speed made good

39. Tests in fine-grained soils and sands with fines, poorly drained. Plots of speed made good versus percent area denied for tests conducted on nearly level fine-grained soils and sands with fines, poorly drained, are shown in plate B4. The curves drawn through the plotted points represent the lines of best visual fit.

40. The comparison of the curves for the wheeled vehicles indicates the highest average speed made good for a given area denied was recorded for the M35A1, lowest for the M37, and the M151 in between. The relative positions of the curves thus differ somewhat from the speed-spacing relation as a result of the width of the vehicle affecting the area denied. The comparison of the curves for the tracked vehicles reflects the same result and for the same reason.

41. Tests in coarse-grained soils. Plots of speed made good versus percent area denied for upslope and downslope tests on coarse-grained soils are shown in plate B5. A line that best separates upslope and downslope test points is drawn on each plot. Examination of the plots shows that, in general, the downslope tests fall above and to the right of the separation line. The total number of plotted points for each set of data, the number that do not fall on the correct side of the separation line, and the percent falling on the proper side are given below. The last column in the tabulation below shows the percent of the total number of points that are on the correct side or safe side. (An upslope speed greater than the line of separation indicates is considered to be on the safe side.)

Vehicle	Total Number of Points	Number Not Conforming	Percent Correct	Percent Correct or on the Safe Side
M151	12	1	92	92
M37	10	1	90	100
M35A1	9	2	78	89
M29C	17	2	88	100
M113	9	0	100	100

From the tabulation above note that only two tests are not on the correct side, and that the overall accuracy is somewhat improved over the comparative mean obstacle spacing plots (paragraphs 31 and 32).

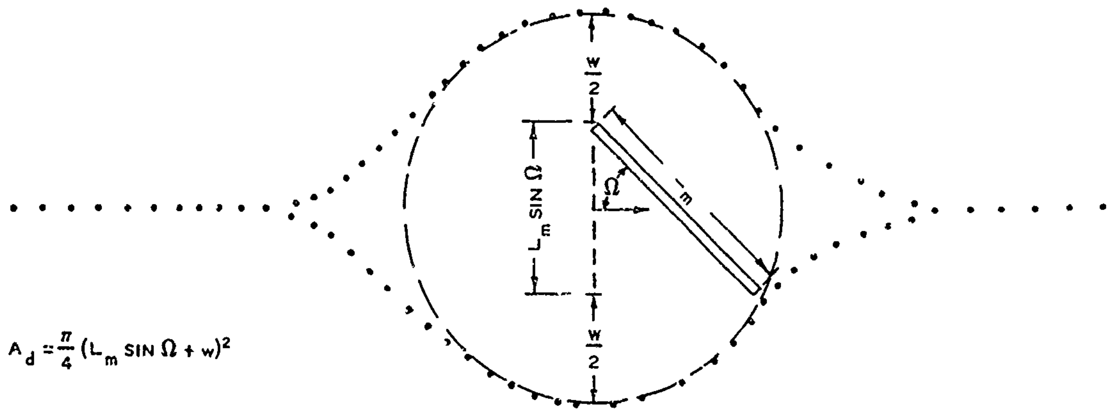
42. A comparison of the performances of the wheeled vehicles is shown in fig. 4, plate B5, and of the tracked vehicles in fig. 7, plate B5. The relative positions of the curves in both figures are the same as in fine-grained soils, plate B4; however, the separation between the curves is distinctly greater. Again this suggests that factors other than those being considered may have significant effect on the speed made good in lateral obstacles.

Other possibilities for use of percent area denied

43. In the tests described herein, all obstacles were tree stems. For other obstacles such as boulders, termite mounds, logs, etc., it is considered possible to apply the area denied principle for all such types

of obstacles by using the following procedures: (a) determine a structural cell diameter D_c for each type of lateral obstacle, e.g. trees, stumps, mounds; (b) convert the area occupied by each lateral obstacle to an equivalent circular area and determine the average diameter $\bar{d}_o$; (c) substitute D_c, $\bar{d}_o$ ($\bar{d}_o$ is equivalent to $\bar{d}_s$), and vehicle width w into the equation given in paragraph 38 and compute the percent area denied; and (d) sum the values of percent area denied computed for each obstacle type to determine the total percent area denied. Trees or boulders occurring within an area denied by logs or termite mounds are excluded from the computation of area denied.

44. The area denied by a log is dependent upon the orientation of the log with respect to the direction of vehicle travel. Fig. B12 illustrates the computation for area denied by a log when the vehicle approaches at an angle Ω. Since the angle Ω is not known, sin Ω is arbitrarily selected as 0.635 which is the average sine of all angles between 0 and 90 deg.



LEGEND

• • • • • • PATH OF POINT ON CENTER LINE OF VEHICLE

L_m = LENGTH OF LOG

Ω = ANGLE FORMED BY LOG AND DIRECTION OF VEHICLE TRAVEL

w = VEHICLE WIDTH

Fig. B12. Example of area denied by log

Notes, Observations, and Other Data Considered

45. Many factors, measurable or unmeasurable, highly significant or

very subtle, can influence the speed made good of a vehicle traversing an area containing lateral obstacles. The following list shows those that are presumed to have some effect. Among those measurable are some for which data can be found in table B2. That these data are not used in the analysis is no reflection on their validity or quality. The effect of the parameters they represent may have been obscured by less subtle influences; current research may bring to light a better understanding of their specific influence.

a. Vehicle factors.

(1) Overall width

(2) Overall length

(3) Wheelbase

(4) Turning radius

(5) Power

(6) Weight

(7) Steering response rate

(8) Mechanical condition

b. Terrain factors.

(1) Size of obstacles

(2) Shape of obstacles

(3) Density of obstacles

(4) Soil strength

(5) Soil surface condition

(6) Slope

(7) Visibility

c. Driver factors.

(1) Recognition distance

(2) Reaction time

(3) Clearance tolerance

(4) Ride dynamics tolerance

46. Equations and empirical relations employing many of the vehicle and terrain factors listed above for use in a first-generation analytical model for predicting speed performance in lateral obstacles have been developed. Vehicle testing programs are being continued to verify the

various relations in the analytical model.

47. The problem of interrelating the factors influencing vehicle performance in lateral obstacles is not lessened when it is realized that the degree of influence of some of the factors varies inversely with the influence of others. For instance, in the tests resulting in low speeds, such vehicle factors as width, length, wheelbase, and turning radius, and such terrain factors as size and spacing of obstacles appeared most significant. In the tests resulting in higher speeds, vehicle and driver factors such as power, weight, steering response rate, and reaction time, and terrain factors such as soil strength, surface condition, slope, and visibility seemed to be of prime importance. From observation only, it was noted that driver influence was most significant when speeds exceeded 8 to 10 mph. Differences in vehicle performances can be demonstrated by comparing the shape of the speed made good versus obstacle spacing curves for the M37 and M35A1 (fig. B13). Below the point of intersection of the two curves speed made good is controlled mainly by vehicle geometry and spacing. Above this point other vehicle and terrain factors begin to assume significance as do the driver factors. Yet the steepness of the M35A1 curve suggests that the vehicle's capability for acceleration exerts influence even at small obstacle spacings.

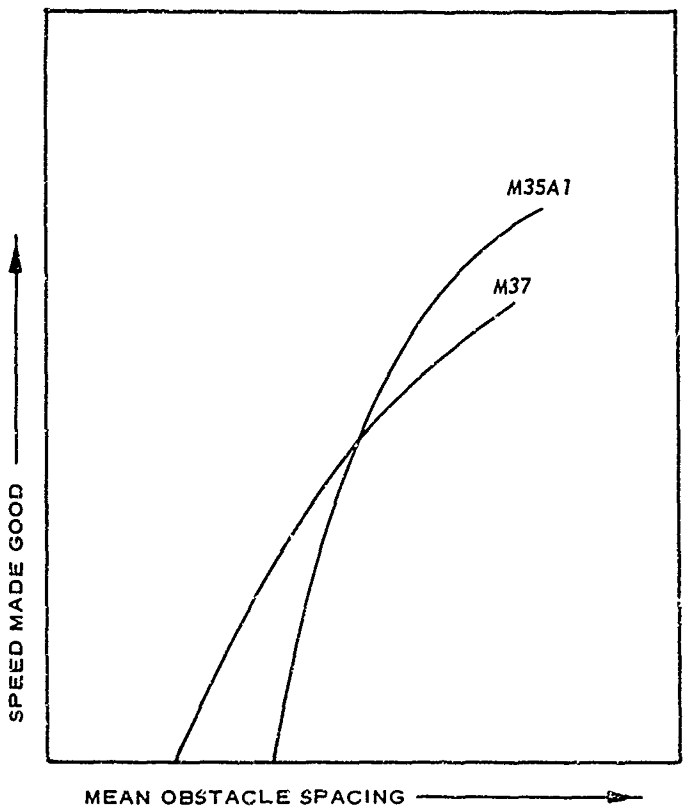


Fig. B13. Comparison of the speed made good-mean obstacle spacing curves for the M37 and M35A1

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

48. Based on the analysis of the data herein and subject to the limits imposed by these data, the following conclusions are offered:

<u>a</u>. Performance of wheeled and tracked vehicles in terms of speed made good in a structurally simple vegetation assemblage can be correlated empirically with the density of the vegetation assemblage expressed as mean obstacle spacing (paragraphs 29-33).

<u>b</u>. The minimum obstacle spacing required to permit movement of standard vehicles is a function of the width of the vehicles (plate B3).

<u>c</u>. Vehicle performance in terms of speed made good in lateral obstacles can be empirically correlated with area denied (paragraphs 39-42).

<u>d</u>. The speed made good that a vehicle can achieve when maneuvering in lateral obstacles is significantly affected by the slope of the terrain (plates B2 and B4).

Recommendations

49. It is recommended that:

<u>a</u>. Tests be conducted in a range of artificial lateral obstacle spacings on a surface sufficiently strong to eliminate the effect of soil strength in order to establish empirical relations between:

(1) Average turning radius and obstacle spacing.

(2) Minimum acceleration required and obstacle spacing.

(3) Average speed and obstacle clearance.

<u>b</u>. Inasmuch as there is some indication that soil strength has a significant effect on vehicle performance in lateral obstacles, additional tests be made to establish speed-spacing relations for a wide range of soil strengths.

<u>c</u>. The relations of <u>a</u> and <u>b</u> above be integrated into the model for predicting vehicle speed in lateral obstacles.

<u>d</u>. Tests be conducted in selected naturally occurring combinations of lateral obstacles and soil strengths to validate the prediction model.

Table B1

Pertinent Vehicle Characteristics

Vehicle	Test Weight lb	Track: Contact Length in.	Track: Width in.	Track: Shoe in.	Contact Pressure psi	Bogies in Contact w/Ground Each Side	Ground Clearance in.	Engine: Type	Engine: Brake Horsepower	Transmission	Width ft	Length ft	Turning Radius ft	Tires: Size	Tires: Ply Rating
M29C	5,600	78	20	6	--	8	11	Gasoline	65	Manual, synchromesh	5.6	16.0	12.0	--	--
M113	19,151-23,896	105	15	6	7.5	5	16.1	Gasoline	215	Hydraulic, single stage, multiphase	8.8	16.0	12.6	--	--
M151	3,000	--	--	--	--	--	9.3	Gasoline	71	Manual, synchromesh	5.2	11.5	17.9	7.00-16	6
M37	7,350-7,645	--	--	--	--	--	10.75	Gasoline	78	Manual, synchromesh	6.1	15.8	26.0	9.00-20	8
M35A1	19,360	--	--	--	--	--	12.7	Multifired	146	Manual, synchromesh	8.0	22.8	36.0	11.00-20	8

Table B2

Summary of Data and Test Re

Test No	Test Site*	Test Date	Straight-Line Distance (D_s) ft	Actual Path Length (D_p) ft	Path Elongation Ratio (D_p/D_s)	Total Time (t) sec	Mean Vegetation Structural Cell Diam ($\bar{D}_c$) ft	Mean Obstacle Spacing (s_e) ft	Percent Area Denied (A_d)	Slope %	Actual Speed mph	Speed Made Good mph	Wheel Slip %	Unified Soil Classification 0- to 6-in. Layer	Unified Soil Classification 6- to 12-in. Layer
M151, 1/4-ton, 4x4 Utility Truck															
240	NASA1	3/29/65	428	434	1.01	16.0	117	26.2	5	0	18.5	18.2	†	ML	CL-ML
241	NASA1	3/29/65	570	580	1.02	24.0	109	24.4	6	0	16.5	16.2	†	ML	CL-ML
242	NASA2	3/30/65	241	245	1.02	15.0	54	12.1	24	0	11.2	11.0	†	ML	CL-ML
243	NASA2	3/30/65	191	218	1.14	11.6	65	14.6	16	0	12.8	11.2	†	ML	CL-ML
251	NASA3	3/31/65	132	143	1.08	42.0	34	7.6	54	0	2.3	2.1	†	ML	CL-ML
269	F4	4/9/65	262	262	1.00	11.5	31	13.7	17	-12.6	15.5	15.5	†	SP	SP
270	E4	4/9/65	237	248	1.05	20.0	68	15.2	13	-11.4	8.4	8.1	†	SP	SP
271	E4	4/9/65	197	197	1.00	9.6	70	15.7	13	+2.0	14.0	14.0	†	SP	SP
278	F3	4/10/65	307	313	1.02	20.5	60	13.4	18	+9.8	10.4	10.2	†	SP	SP
279	E3	4/10/65	296	307	1.04	20.4	58	13.0	19	+9.8	10.3	9.9	†	SP	SP
280	E3	4/10/65	192	198	1.03	12.9	51	11.4	24	-0.5	10.5	10.1		SP	SP
283A	E2	4/13/65	400	450	1.12	45.0	52	11.6	26	+7.5	6.8	6.1	†	SP	SP
284	E2	4/13/65	412	421	1.02	30.5	46	10.8	30	-6.6	9.4	9.2	†	SP	SP
294	E1	4/14/65	186	194	1.04	13.4	48	10.8	28	-8.1	9.9	9.5	†	SP	SP
295	E1	4/14/65	310	317	1.02	17.0	69	15.5	14	-2.6	12.7	12.4	†	SP	SP
296	E1	4/14/65	167	172	1.03	10.5	86	19.3	9	+11.4	11.2	10.8	†	SP	SP
297	E1	4/14/65	320	331	1.03	19.0	61	13.7	17	+1.6	11.9	11.5	†	SP	SP
M37, 3/4-ton, 4x4 Cargo Tr															
1	NASA1	7/29/64	442	446	1.01	22.2	118	26.4	6	0	13.7	13.6	0	ML	CL-ML
2	NASA1	7/29/64	782	789	1.01	39.7	106	23.7	8	0	13.6	13.4	0	ML	CL-ML
9	NASA2	8/5/64	520	531	1.02	47.3	62	13.9	24	0	7.6	7.5	0	ML	CL-ML
10	NASA2	8/5/64	471	479	1.02	50.0	61	13.7	25	0	6.5	6.4	0	ML	CL-ML
12	NASA3	3/5/64	290	†	†	†	30	6.7	93	0	0	0	†	ML	CL-ML
13A	NASA3	8/5/64	294	†	†	†	38	8.5	58	0	0.2	0.2	†	ML	CL-ML
13B	NASA3	8/5/64	294	†	†	†	36	8.1	64	0	0	0	†	ML	CL-ML
22	NASA4	8/18/64	587	597	1.02	35.0	80	17.9	15	0	11.6	11.4	†	SM	SM
23	NASA4	8/18/64	552	570	1.03	35.0	77	17.2	16	0	11.1	10.8	†	SM	SM
265	E1	4/8/65	281	294	1.05	23.4	73	16.4	16	+6.8	8.5	8.2	††	SP	SP
266	E1	4/8/65	289	297	1.03	18.9	73	16.4	16	-2.2	10.7	10.4	††	SP	SP
267	E1	4/8/65	240	257	1.07	18.8	71	15.9	17	+1.9	9.3	8.7	††	SP	SP
272	E4	4/9/65	216	229	1.06	14.0	68	15.[illegible]	18	-11.9	11.2	10.5	4	SP	SP
273	E4	4/9/65	197	200	1.02	14.0	64	14.3	20	+10.2	9.8	9.6	††	SP	SP
274	E4	4/9/65	156	170	1.09	13.9	65	14.6	20	+5.6	8.3	7.7	5	SP	SP
275	E3	4/9/65	232	242	1.04	27.6	52	11.6	34	+9.5	6.0	5.7	5	SP	SP
276	E3	4/9/65	287	294	1.02	23.8	54	12.1	29	-8.3	8.4	8.2	0	SP	SP
277	E3	4/9/65	146	162	1.11	18.9	63	14.1	21	+3.2	5.8	5.3	4	SP	SP
281	E2	4/12/65	386	410	1.06	61.3	55	12.3	30	+5.9	4.6	4.3	3	SP	SP
282	E2	4/12/65	408	496	1.22	††	†		†	-5.6	†	†	††	SP	SP
M35A1, 2-1/2-ton, 6x6 Cargo															
252	NASA2	3/31/65	254	259	1.02	28.0	64	14.3	37	0	6.3	6.2	7	ML	CL-ML
253	NASA2	4/1/65	445	472	1.06	39.0	66	14.8	35	0	8.3	7.8	0	ML	CL-ML
263	NASA1	4/5/65	649	653	1.01	28.0	105	23.5	13	0	15.9	15.8	0	ML	CL-ML
264	NASA1	4/5/65	707	735	1.04	37.0	106	23.7	13	0	13.5	13.0	0	ML	CL-ML
285	E3	4/13/65	144	150	1.04	23.7	55	12.3	47	+9.6	4.3	4.1	1	SP	SP
286	E3	4/13/65	124	128	1.03	37.9	52	11.6	53	-8.5	2.3	2.2	0	SP	SP
287	E4	4/13/65	184	187	1.02	9.7	68	15.2	30	-10.3	13.2	12.9	0	SP	SP
288	E4	4/13/65	185	189	1.02	28.3	62	13.9	36	+9.3	4.6	4.5	6	SP	SP
289	E4	4/13/65	148	154	1.04	14.3	70	15.7	28	+2.8	7.4	7.1	3	SP	SP
290	E1	4/14/65	173	175	1.01	9.5	73	16.4	27	+2.2	12.5	12.4	5	SP	SP
291	E1	4/14/65	347	366	1.05	30.0	73	16.4	27	-4.9	8.3	7.9	0	SP	SP
292	E1	4/14/65	168	169	1.01	14.3	72	16.1	28	+7.4	8.1	8.0	4	SP	SP
293	E	4/14/65	142	146	1.03	14.3	58	13.0	43	+0.6	6.9	6.8	4	SP	SP

* See description in text of test areas and test sites.

** C_{rl} = cohesion (psi), rubber to litter, ϕ_{rl} = friction angle (degrees), rubber to litter, C_{rs} = cohesion (psi), rubber to soil, ϕ_{rs} = friction angle (degrees), r

† No measurement made.

†† Instrumentation failure.

A

Table B2

Summary of Data and Test Results

Slope %	Actual Speed mph	Speed Made Good mph	Wheel Slip %	Unified Soil Classification: 0- to 6-in. Layer	Unified Soil Classification: 6- to 12-in. Layer	Average Cone Index at Depths, in.: 0	3	6	9	12	15	18	Rating Cone Index: 0- to 6-in. Layer	Rating Cone Index: 6- to 12-in. Layer	Sheargraph Data**: C_{rl}	ϕ_{rl}	C_{rs}	ϕ_{rs}	C_{ss}	ϕ_{ss}	Moisture Content, Percent of Dry Soil Weight: 0- to 1-in. Layer	0- to 6-in. Layer	6- to 12-in. Layer	Dry Density pcf: 0- to 6-in. Layer	6- to 12-in. Layer
M151, 1/4-ton, 4x4 Utility Truck (Jeep)																										
0	18.5	18.2	†	ML	CL-ML	40	69	73	89	87	84	103	23	34	2.0	33.0	0	20	†	†	58.1	34.6	30.5	81.8	87.6
0	16.5	16.2	†	ML	CL-ML	28	70	67	66	68	79	83	19	26	0.7	38.0	0.3	21	1.1	16	59.4	36.3	25.7	80.9	93.7
0	11.2	11.0	†	ML	CL-ML	61	107	94	84	94	110	109	29	32	1.6	28.0	0.9	20	0.9	29	63.5	32.2	25.5	78.2	91.2
0	12.8	11.2	†	ML	CL-ML	59	99	88	78	72	85	98	27	33	1.6	28.0	0.9	20	0.9	29	50.2	27.6	24.5	83.8	92.8
0	2.3	2.1	†	ML	CL-ML	73	191	219	195	197	210	210	47	59	0	34.0	0	28	0	20	44.2	26.7	20.5	83.8	97.4
-12.6	15.5	15.5	†	SP	SP	34	78	78	73	65	70	75	†	†	0	27.0	0	27	0	28	14.2	5.7	5.9	91.2	94.8
+11.4	8.4	8.1	†	SP	SP	32	64	75	67	73	77	81	†	†	0	30.0	0	23	0	25	3.9	3.7	4.8	91.2	92.8
+2.0	14.0	14.0	†	SP	SP	33	71	76	70	69	73	78	†	†	0	28.0	0	25	0	25	9.0	4.7	5.3	91.2	93.8
+9.8	10.4	10.2	†	SP	SP	30	78	68	70	78	77	90	†	†	0	32.0	0	28	0	28	4.4	5.9	5.2	86.2	93.7
+9.8	10.3	9.9	†	SP	SP	27	86	87	72	66	74	84	†	†	0	27.0	0	24	0	25	4.5	4.1	4.3	89.1	90.[illegible]
-0.5	10.5	10.1	†	SP	SP	29	82	78	71	72	75	87	†	†	0	27.0	0	24	0	25	4.5	5.0	4.7	87.5	91.5
+7.5	6.8	6.1	†	SP	SP	53	146	146	136	146	198	263	†	†	0	30.0	0	25	0	30	5.5	6.2	5.8	89.6	98.3
-6.6	9.4	9.2	†	SP	SP	53	146	146	136	146	198	263	†	†	0	30.0	0	25	0	30	5.5	6.2	5.8	89.6	98.3
-8.1	9.9	9.5	†	SP	SP	32	99	128	116	109	115	125	†	†	1.7	23.0	0	25	0	24	1.7	3.7	4.8	88.7	92.9
-2.6	12.7	12.4	†	SP	SP	32	92	87	108	115	114	123	†	†	0.3	25.0	0	22	0	28	2.8	7.3	5.3	87.[illegible]	97.0
+11.4	11.2	10.8	†	SP	SP	32	92	87	108	115	114	123	†	†	0.3	25.0	0	22	0	28	2.8	7.3	5.3	87.6	97.0
+1.6	11.9	11.5	†	SP	SP	32	99	128	116	109	115	125	†	†	1.7	23.0	0	25	0	24	1.7	3.7	4.8	88.7	92.9
M37, 3/4-ton, 4x4 Cargo Truck																										
0	13.7	13.6	0	ML	CL-ML	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†
0	13.6	13.4	0	ML	CL-ML	48	112	108	103	115	132	146	22	26	0	45.0	1.7	24	1.7	30	†	37.5	24.5	82.[illegible]	87.0
0	7.6	7.5	0	ML	CL-ML	118	241	192	180	196	243	250	†	†	†	†	0	34	0	43	†	†	†	†	†
0	6.5	6.4	0	ML	CL-ML	82	176	170	172	188	218	194	26	26	†	†	0	37	0	40	†	34.4	28.9	84.4	90.2
0	0	0	†	ML	CL-ML	125	209	219	250	264	†	†	†	†	0.2	36.0	0	37	0.3	44	†	21.0	19.1	88.7	100.4
0	0.2	0.2	†	ML	CL-ML	187	342	418	379	327	†	†	†	†	0.2	36.0	0	37	0.3	44	†	22.9	18.5	81.8	104.3
0	0	0	†	ML	CL-ML	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†
0	11.6	11.4	†	SM	SM	41	132	250	340	362	360	381	†	†	0	38.0	0	33	0	42	†	17.6	13.2	90.7	108.3
0	11.1	10.8	†	SM	SM	62	222	315	354	384	395	410	†	†	0	37.0	0	34	0	42	†	23.6	12.4	84.6	102.3
+6.8	8.5	8.2	††	SP	SP	26	82	93	93	105	114	125	†	†	0	32.0	0	30	0	36	4.0	5.9	6.2	89.4	9[illegible]
-2.2	10.7	10.4	††	SP	SP	27	84	103	110	120	145	174	†	†	0	35.0	0	25	0	30	28.4	16.9	13.1	84.6	97.1
+1.9	9.3	8.7	††	SP	SP	27	84	103	110	120	145	174	†	†	0	31.0	0	25	0	31	28.4	16.9	13.1	84.6	97.1
-11.9	11.2	10.5	4	SP	SP	34	78	78	73	65	70	75	†	†	0	27.0	0	27	0	28	14.2	5.7	5.9	91.2	94.8
+10.2	9.8	9.6	††	SP	SP	32	64	75	67	73	77	81	†	†	0	30.0	0	23	0	25	3.9	3.7	4.8	91.2	92.8
+5.6	8.3	7.7	5	SP	SP	33	71	76	70	69	73	78	†	†	0	28.0	0	25	0	26	9.0	4.7	5.3	91.2	93.8
+9.5	6.0	5.7	5	SP	SP	30	83	81	69	73	74	80	†	†	0	29.0	0	25	0	32	5.7	6.9	5.8	93.9	95.3
-8.3	8.4	8.2	0	SP	SP	26	88	84	75	80	92	99	†	†	0	29.0	0	22	0	26	3.1	3.1	4.8	88.2	90.7
+3.2	5.8	5.3	4	SP	SP	28	85	82	72	76	83	90	†	†	0	29.0	0	23	0	29	4.4	5.0	5.3	91.1	93.0
+5.9	4.6	4.3	3	SP	SP	53	146	146	136	146	198	263	†	†	0	30.0	0	25	0	30	5.5	6.2	5.8	89.6	98.3
-5.6	†	†	††	SP	SP	53	146	146	136	146	198	263	†	†	0	30.0	0	25	0	30	5.5	6.2	5.8	89.6	98.3
M35A1, 2-1/2-ton, 6x6 Cargo Truck																										
0	6.3	6.2	7	ML	CL-ML	44	74	76	60	68	93	96	23	40	1.7	27.0	0	19	1.3	16	56.4	30.0	23.2	84.6	98.6
0	8.3	7.8	0	ML	CL-ML	76	137	119	82	88	96	100	40	37	0	35.0	0	25	0.9	30	43.2	30.5	27.3	78.7	84.4
0	15.9	15.8	0	ML	CL-ML	41	81	85	73	76	77	82	29	28	3.0	25.0	0	19	1.0	15	50.9	36.9	25.8	77.3	91.0
0	13.5	13.0	0	ML	CL-ML	39	84	85	70	70	72	78	31	29	3.0	26.0	0	19	0.9	14	51.7	35.2	25.5	79.9	92.9
+9.6	4.3	4.1	1	SP	SP	33	94	78	74	76	79	87	†	†	0.7	23.0	0	[illegible]	0	35	3.9	5.4	5.5	90.1	94.1
-8.5	2.3	2.2	0	SP	SP	40	96	93	92	88	92	96	†	†	0	24.0	0	26	0	28	1.6	3.9	3.9	85.6	90.5
-10.3	13.2	12.9	0	SP	SP	55	173	289	374	380	377	349	†	†	0	25.0	0	20	0	26	1.5	2.9	3.3	92.6	101.2
+9.3	4.6	4.5	6	SP	SP	26	87	76	80	80	78	75	†	†	0	29.0	0	26	0	27	2.4	2.9	3.4	88.8	91.8
+2.8	7.4	7.1	3	SP	SP	40	130	182	227	23[illegible]	227	212	†	†	0	27.0	0	23	0	26	2.0	2.9	3.4	90.7	9[illegible].5
+2.2	12.6	12.4	5	SP	SP	32	42	87	108	1[illegible]5	114	123	†	†	0.3	25.0	0	22	0	28	2.8	7.[illegible]	5.[illegible]	87.6	97.0
-4.9	8.3	7.9	0	SP	SP	32	42	87	108	115	114	123	†	†	0.3	25.0	0	22	0	28	2.8	7.3	5.3	87.6	97.0
+7.4	8.1	8.0	4	SP	SP	32	99	128	116	109	115	125	†	†	1.7	23.0	0	25	0	24	1.[illegible]	3.7	4.8	88.7	92.9
+0.6	6.9	6.8	4	SP	SP	32	99	128	116	109	115	125	†	†	1.7	23.0	0	25	0	24	1.7	3.7	4.8	88.7	92.[illegible]

i), rubber to soil, ϕ_{rs} = friction angle (degrees), rubber to soil; C_{ss} = cohesion (psi), soil to soil; ϕ_{ss} = frictic . angle (degre.s), soil to soil.

Table B2 (Concluded)

Test No.	Test Site	Test Date	Straight-Line Distance (D_s) ft	Actual Path Length (D_p) ft	Path Elongation Ratio (D_p/D_s)	Total Time (t) sec	Mean Vegetation Structural Cell Diam ($\bar{D}_c$) ft	Mean Obstacle Spacing (s_e) ft	Percent Area Denied (A_d)	Slope %	Actual Speed mph	Speed Made Good mph	Wheel Slip %	Unified Soil Classification 0- to 6-in. Layer	Unified Soil Classification 6- to 12-in. Layer	Average Cone Index 0	3	6	9
												M29C, Amphibious Cargo Carrier (Weasel)							
4	NASA1	7/31/64	612	618	1.01	27.5	103	23.1	7	0	15.3	15.2	0	ML	CL-ML	51	93	100	92
5	NASA1	7/31/64	558	560	1.00	27.5	107	24.0	7	0	13.9	13.8	0	ML	CL-ML	39	80	81	82
6	NASA2	8/3/64	405	408	1.01	43.4	59	13.2	23	0	6.4	6.4	0	ML	CL-ML	112	196	201	200
7	NASA2	8/3/64	453	483	1.07	40.0	61	13.7	21	0	8.2	7.7	0	ML	CL-ML	150	261	275	270
8A	NASA2	8/21/64	292	316	1.08	23.8	61	13.7	21	0	9.0	8.4	0	ML	CL-ML	48	95	78	69
15A	NASA3	8/21/64	295	†	†	†	34	7.6	62	0	0.2	0.2	0	ML	CL-ML	136	183	191	144
15B	NASA3	8/21/64	295	†	†	†	31	6.9	75	0	0	0	0	ML	CL-ML	†	†	†	†
19	NASA4	8/20/64	562	570	1.01	34.9	74	16.6	15	0	11.1	11.0	0	SM	SM	71	173	297	280
20	NASA4	8/20/64	549	556	1.01	36.8	72	16.1	16	0	10.3	10.2	0	SM	SM	74	169	224	246
301	E1	4/15/65	150	153	1.02	13.9	71	15.9	15	+10.1	7.5	7.4	††	SP	SP	42	112	116	120
304	E1	4/15/65	216	218	1.01	13.7	63	14.1	19	+0.6	10.9	10.7	††	SP	SP	32	94	93	101
305	E1	4/15/65	196	200	1.02	13.7	62	13.9	19	-7.8	9.9	9.8	††	SP	SP	42	112	116	120
306	E4	4/16/65	139	140	1.01	8.9	65	14.6	17	-2.7	10.7	10.6	††	SP	SP	29	75	87	98
307	E4	4/16/65	214	218	1.02	13.3	63	14.1	18	-12.6	11.2	11.0	††	SP	SP	29	75	87	98
308	E4	4/16/65	230	233	1.01	19.0	63	14.1	18	+12.6	8.4	8.3	††	SP	SP	29	75	87	98
309	E4	4/16/65	214	218	1.02	13.4	60	13.4	20	-11.0	11.1	10.9	††	SP	SP	32	92	81	83
310	E1	4/16/65	250	253	1.01	19.0	67	15.0	16	+12.0	9.1	9.0	††	SP	SP	32	92	81	83
311	E3	4/16/65	287	294	1.02	27.3	56	12.5	23	+9.5	7.3	7.2	††	[illegible]	SP	41	99	116	101
312	E3	4/16/65	212	215	1.01	18.2	48	10.8	31	-5.6	8.0	7.9	††	SP	SP	41	99	116	101
313	E3	4/16/65	136	136	1.00	9.1	51	11.4	28	-1.0	10.3	10.2	††	SP	SP	36	125	116	80
314	E3	4/16/65	280	286	1.02	22.9	58	13.0	22	+9.6	8.5	8.3	††	SP	SP	36	125	116	80
315	E3	4/16/65	124	137	1.10	16.1	46	10.3	34	-8.1	5.8	5.3	††	SP	SP	36	125	116	80
321	E2	4/17/65	386	414	1.07	62.8	49	11.0	33	+7.2	4.5	4.2	††	SP	SP	76	155	130	113
322	E2	4/17/65	299	308	1.03	45.2	44	9.9	40	-6.9	4.7	4.5	††	SP	SP	71	210	221	213
323	E2	4/17/65	251	290	1.16	34.8	44	9.9	40	+7.5	5.7	4.9	††	SP	SP	76	155	130	113
324	E2	4/17/65	86	86	1.00	9.0	44	9.9	40	-1.3	6.5	6.5	††	SP	SP	76	155	130	113
												M113, Armored Personnel Carrier (APC)							
25	NASA1	11/23/64	884	897	1.01	32.5	167	37.4	6	0	18.8	18.5	0	ML	CL-ML	70	112	127	120
26	NASA1	11/23/64	744	750	1.01	26.3	183	41.0	5	0	19.4	19.3	0	ML	CL-ML	60	105	112	122
27	NASA1	11/23/64	509	514	1.01	21.0	159	35.6	7	0	16.7	16.5	0	ML	CL-ML	56	69	69	79
28	NASA1	11/23/64	842	855	1.02	27.1	166	37.2	6	0	21.5	21.2	0	ML	CL-ML	62	98	91	91
29	NASA2	11/24/64	506	558	1.10	143.8	68	15.2	39	0	2.6	2.4	0	ML	CL-ML	99	247	200	178
30	NASA2	11/24/64	419	555	1.32	98.0	61	13.7	48	0	3.9	2.9	0	ML	CL-ML	113	171	156	180
31	NASA2	11/24/64	241	245	1.02	16.8	70	15.7	37	0	9.9	9.8	0	ML	CL-ML	†	†	†	†
32	NASA2	11/24/64	494	535	1.08	147.7	58	13.0	54	0	2.5	2.3	0	ML	CL-ML	109	186	157	168
256	NASA4	4/1/65	556	571	1.03	38.0	78	17.5	30	0	10.3	10.0	0	SM	SM	25	71	91	101
257	NASA4	4/1/65	606	635	1.05	52.3	79	17.7	30	0	8.3	7.9	0	SM	SM	31	60	86	107
325	E1	4/19/65	142	174	1.22	14.0	60	15.5	36	+0.9	8.5	6.9	0	SP	SP	†	†	†	†
326	E1	4/19/65	162	180	1.11	13.8	71	15.9	34	-9.5	8.9	8.0	0	SP	SP	28	74	86	89
328	E1	4/19/65	242	256	1.06	23.2	80	17.9	27	+8.5	7.5	7.1	4	SP	SP	28	66	72	66
330	E1	4/20/65	145	148	1.02	13.8	76	17.0	30	+10.8	7.3	7.2	0	SP	SP	31	74	81	76
331	E4	4/21/65	179	194	1.08	16.5	67	15.0	37	-2.2	8.0	7.4	0	SP	SP	32	70	80	62
332	E4	4/21/65	191	203	1.06	14.0	69	15.5	35	-11.9	9.9	9.3	0	SP	SP	28	65	71	84
333	E4	4/21/65	180	182	1.01	18.8	73	16.4	31	+11.9	6.6	6.5	2	SP	SP	32	70	80	62
334	E4	4/21/65	212	236	1.11	13.1	72	16.1	32	-10.5	12.3	11.0	0	SP	SP	26	64	93	120
335	E4	4/21/65	182	186	1.02	18.7	69	15.5	35	+12.6	6.8	6.6	1	SP	SP	32	70	80	62

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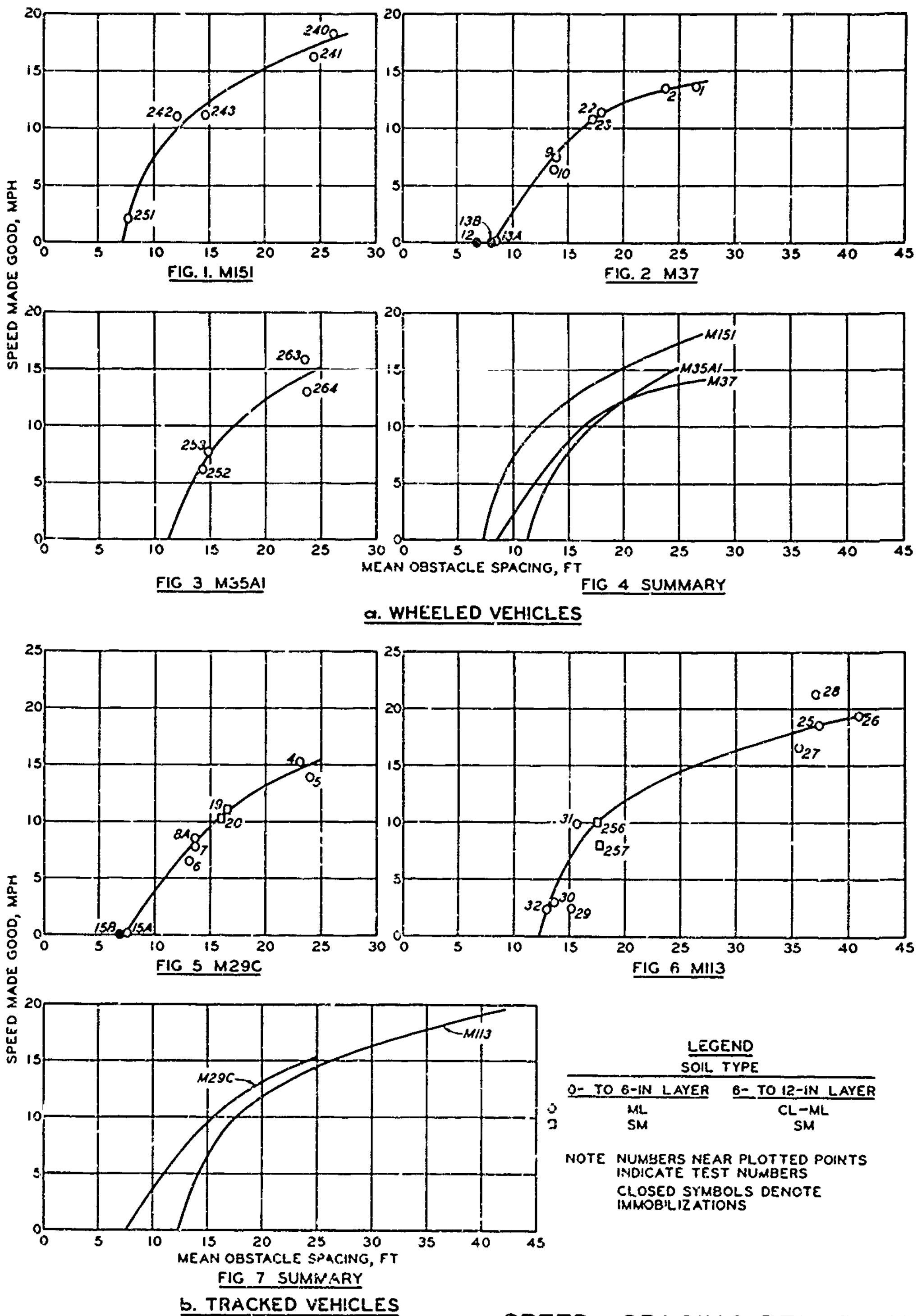
† No measurement made.
†† Instrumentation failure.

Table B2 (Concluded)

…e	Actual Speed mph	Speed Made Good mph	Wheel Slip %	Unified Soil Classification 0- to 6-in. Layer	Unified Soil Classification 6- to 12-in. Layer	Average Cone Index at Depths, in. 0	3	6	9	12	15	18	Soils Data: Rating Cone Index 0- to 6-in. Layer	Rating Cone Index 6- to 12-in. Layer	Sheargraph Data C_{rl}	ϕ_{rl}	C_{rs}	ϕ_{rs}	C_{ss}	ϕ_{ss}	Moisture Content Percent of Dry Soil Weight 0- to 1-in. Layer	0- to 6-in. Layer	6- to 12-in. Layer	Dry Density pcf 0- to 6-in. Layer	6- to 12-in. Layer
	M29C, Amphibious Cargo Carrier (Weasel)																								
	15.3	15.2	0	ML	CL-ML	51	93	100	92	97	152	124	33	34	0	41.0	3.5	27	2.0	14	†	35.0	26.4	80.1	90.1
	13.9	13.8	0	ML	CL-ML	39	80	81	82	82	104	113	23	38	†	†	†	†	†	†	†	36.9	27.5	79.3	89.5
	6.4	6.4	0	ML	CL-ML	112	196	201	200	197	205	215	22	34	0.5	31.0	0	35	1.5	36	†	24.0	86.5	--	98.2
	8.2	7.7	0	ML	CL-ML	150	261	275	270+	274+	273+	282+	†	†	0.5	31.0	0	35	1.5	36	†	23.1	19.7	85.2	97.0
	9.0	6.4	0	ML	CL-ML	48	95	78	69	118	109	116	29	41	1.2	43.5	0.9	33	1.8	38	†	29.0	24.6	87.1	95.7
	0.2	0.2	0	ML	CL-ML	136	183	191	144	146	†	†	†	†	†	†	†	†	†	†	†	23.5	20.0	85.3	100.0
	0	0	0	ML	CL-ML	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†
	11.1	11.0	0	SM	SM	71	173	297	280	279	285	282	†	†	1.0	38.0	1.6	27	3.4	32	-	16.9	15.0	88.9	95.5
	10.3	10.2	0	SM	SM	74	169	224	246	251	[illegible]	272	†	†	1.0	36.5	1.2	41	1.1	47	--	21.1	19.3	87.9	95.9
.1	7.5	7.4	††	SP	SP	42	112	116	120	160	231	283	†	†	0	32.0	0	26	0	31	33.9	20.9	12.6	85.7	98.2
.6	10.9	10.7	††	SP	SP	32	94	93	101	105	103	105	†	†	0	30.0	0	26	0	29	6.1	6.0	4.4	92.6	98.0
.8	9.9	9.8	††	SP	SP	42	112	116	120	160	231	283	†	†	0	32.0	0	26	0	31	33.9	20.9	12.6	85.7	98.2
.7	10.7	10.6	††	SP	SP	29	75	87	98	99	105	107	†	†	0	20.0	0	22	0	27	2.8	4.4	1.6	93.8	97.1
.6	11.2	11.0	††	SP	SP	29	75	87	98	99	105	107	†	†	0	20.0	0	22	0	27	2.8	4.4	1.6	93.8	97.1
.6	8.4	8.3	††	SP	SP	29	75	87	98	99	105	107	†	†	0	20.0	0	22	0	27	2.8	4.4	1.6	93.8	97.1
.0	11.1	10.9	††	SP	SP	32	92	81	83	82	83	89	†	†	0	26.0	0	21	0	26	4.5	3.9	3.6	89.0	94.0
.0	9.1	9.0	††	SP	SP	32	92	81	83	82	83	89	†	†	0	26.0	0	21	0	26	4.5	3.9	3.6	89.0	94.0
.5	7.3	7.2	††	SP	SP	41	99	116	101	101	94	100	†	†	1.0	23.0	0	19	0	30	0.9	2.1	3.2	93.6	96.6
.6	8.0	7.9	††	SP	SP	41	99	116	101	101	94	100	†	†	1.0	23.0	0	19	0	30	0.9	2.1	3.2	93.6	96.6
.0	10.3	10.2	††	SP	SP	36	125	116	80	89	100	100	†	†	0	26.0	0	28	0	34	6.0	3.8	4.5	90.7	93.6
.6	8.5	8.3	††	SP	SP	36	125	116	80	89	100	100	†	†	0	26.0	0	28	0	34	6.0	3.8	4.5	90.7	93.6
.1	5.8	5.3	††	SP	SP	36	125	116	80	89	100	100	†	†	0	26.0	0	28	0	34	6.0	3.8	4.5	90.7	93.6
.2	4.5	4.2	††	SP	SP	76	155	130	113	116	162	254	†	†	0	22.0	0	24	0	31	3.7	7.4	8.3	80.5	93.5
.9	4.7	4.5	††	SP	SP	71	210	221	213	238	413	468	†	†	0	30.0	0	25	0	34	3.4	8.1	8.4	84.3	97.9
.5	5.7	4.9	††	SP	SP	76	155	130	113	116	162	254	†	†	0	22.0	0	24	0	31	3.7	7.4	8.3	80.5	93.5
.3	6.5	6.5	††	SP	SP	76	155	130	113	116	162	254	†	†	0	22.0	0	24	0	31	3.7	7.4	8.3	80.5	93.5
	M113, Armored Personnel Carrier (APC)																								
	18.6	18.5	0	ML	CL-ML	70	112	127	120	133	155	166	†	†	†	†	†	†	†	†	†	31.6	23.5	80.7	92.9
	19.4	19.3	0	ML	CL-ML	60	105	112	122	133	144	151	†	†	†	†	†	†	†	†	†	33.9	25.1	78.9	91.0
	16.7	16.5	0	ML	CL-ML	56	69	69	79	94	111	126	†	†	†	†	†	†	†	†	†	34.1	24.4	81.8	93.9
	21.5	21.2	0	ML	CL-ML	62	98	91	91	99	123	144	†	†	†	†	†	†	†	†	†	31.6	23.1	81.3	93.4
	2.6	2.4	0	ML	CL-ML	99	247	200	178	[illegible]	213	245	†	†	†	†	†	†	†	†	†	20.9	20.0	87.6	98.0
	3.9	2.9	0	ML	CL-ML	113	171	156	160	208	227	233	†	†	†	†	†	†	†	†	†	23.6	19.3	86.8	99.1
	9.9	9.8	0	ML	CL-ML	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†
	2.5	2.3	0	ML	CL-ML	109	186	157	168	208	218	247	†	†	†	†	†	†		†	†	22.6	21.0	87.6	98.0
	10.3	10.0	0	SM	SM	25	71	91	101	102	111	119	11	16	†	†	†	†	†	†	47.4	27.6	17.4	88.8	104.1
	8.3	7.9	0	SM	SM	31	60	86	107	108	128	144	9	17	†	†	†	†	†	†	46.4	25.5	17.6	89.6	102.7
.9	8.5	6.9	0	SP	SP	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†	†
.5	8.9	8.0	0	SP	SP	28	74	86	89	90	95	99	†	†	0	26.0	0	25	0	26	8.1	9.1	7.6	87.9	97.3
.5	7.5	7.1	4	SP	SP	28	66	72	66	72	79	87	†	†	0	35.0	0	24	0	28	8.5	9.5	8.8	86.0	89.3
.8	7.3	7.2	0	SP	SP	31	74	81	76	86	102	120	†	†	0.7	30.0	0	24	0	26	7.3	9.1	10.1	89.6	89.4
.2	8.0	7.4	0	SP	SP	32	70	80	62	77	70	82	†	†	0	25.0	0	26	0	26	8.7	5.9	3.7	87.1	94.1
.9	9.9	9.3	0	SP	SP	28	65	71	84	105	98	119	†	†	0	25.0	0	23	0	21	1.9	5.1	6.4	88.3	90.[illegible]
.9	6.6	6.5	2	SP	SP	32	70	80	62	77	70	82	†	†	0	25.0	0	26	0	26	6.7	5.9	3.7	87.1	94.1
.5	12.3	11.0	0	SP	SP	26	64	93	120	173	130	185	†	†	0	29.0	0	24	0	23	5.5	5.9	3.9	91.8	94.4
.6	6.8	6.6	1	SP	SP	32	70	80	62	77	70	82	†	†	0	25.0	0	26	0	26	8.7	5.9	3.7	87.1	94.1

D



SPEED - SPACING RELATIONS
SPEED MADE GOOD VS
MEAN OBSTACLE SPACING
TESTS ON FINE-GRAINED SOILS AND SANDS WITH FINES, POORLY DRAINED
NEARLY LEVEL SURFACES

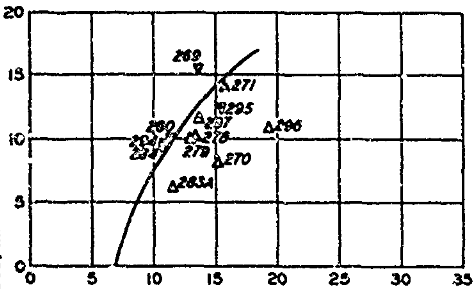


FIG. 1. M151

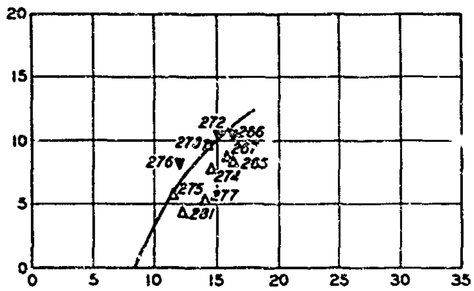


FIG. 2. M37

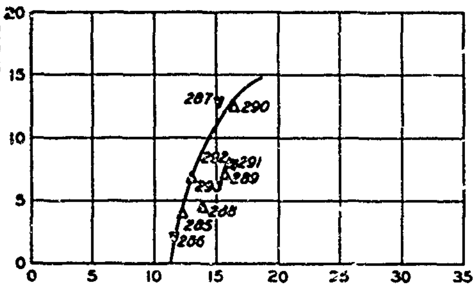
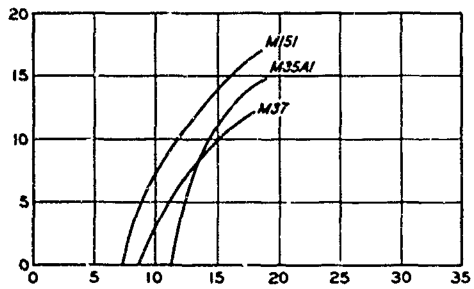


FIG. 3. M35A1



MEAN OBSTACLE SPACING, FT

FIG. 4. SUMMARY

SPEED MADE GOOD, MPH

a. WHEELED VEHICLES

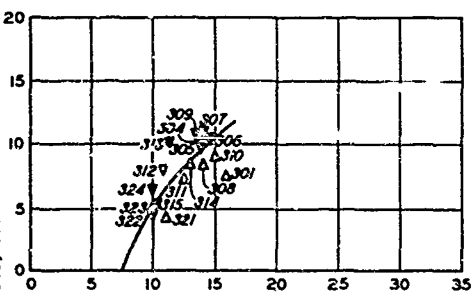


FIG. 5. M29C

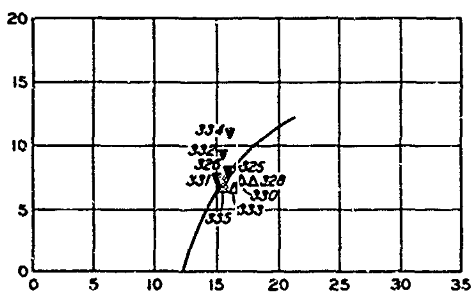
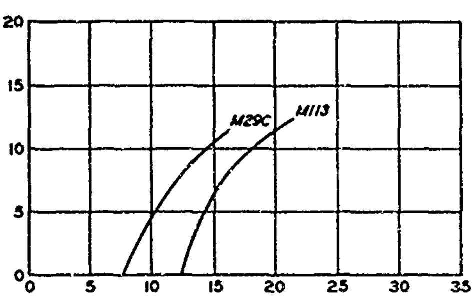


FIG. 6. M113



SPEED MADE GOOD, MPH

MEAN OBSTACLE SPACING, FT

FIG. 7. SUMMARY

b. TRACKED VEHICLES

LEGEND

SOIL TYPE SP

Δ UPSLOPE

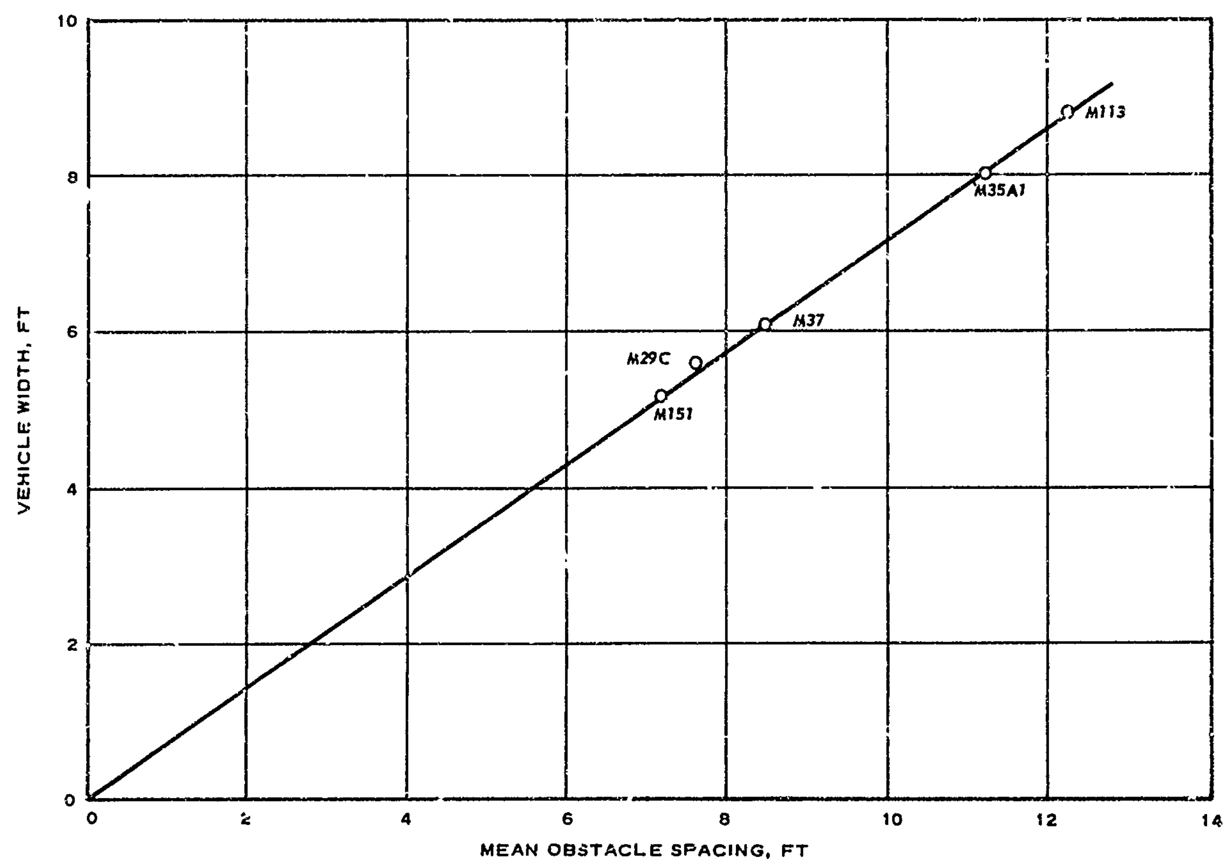
▼ DOWNSLOPE

NOTE. NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBERS.

SPEED-SPACING RELATIONS

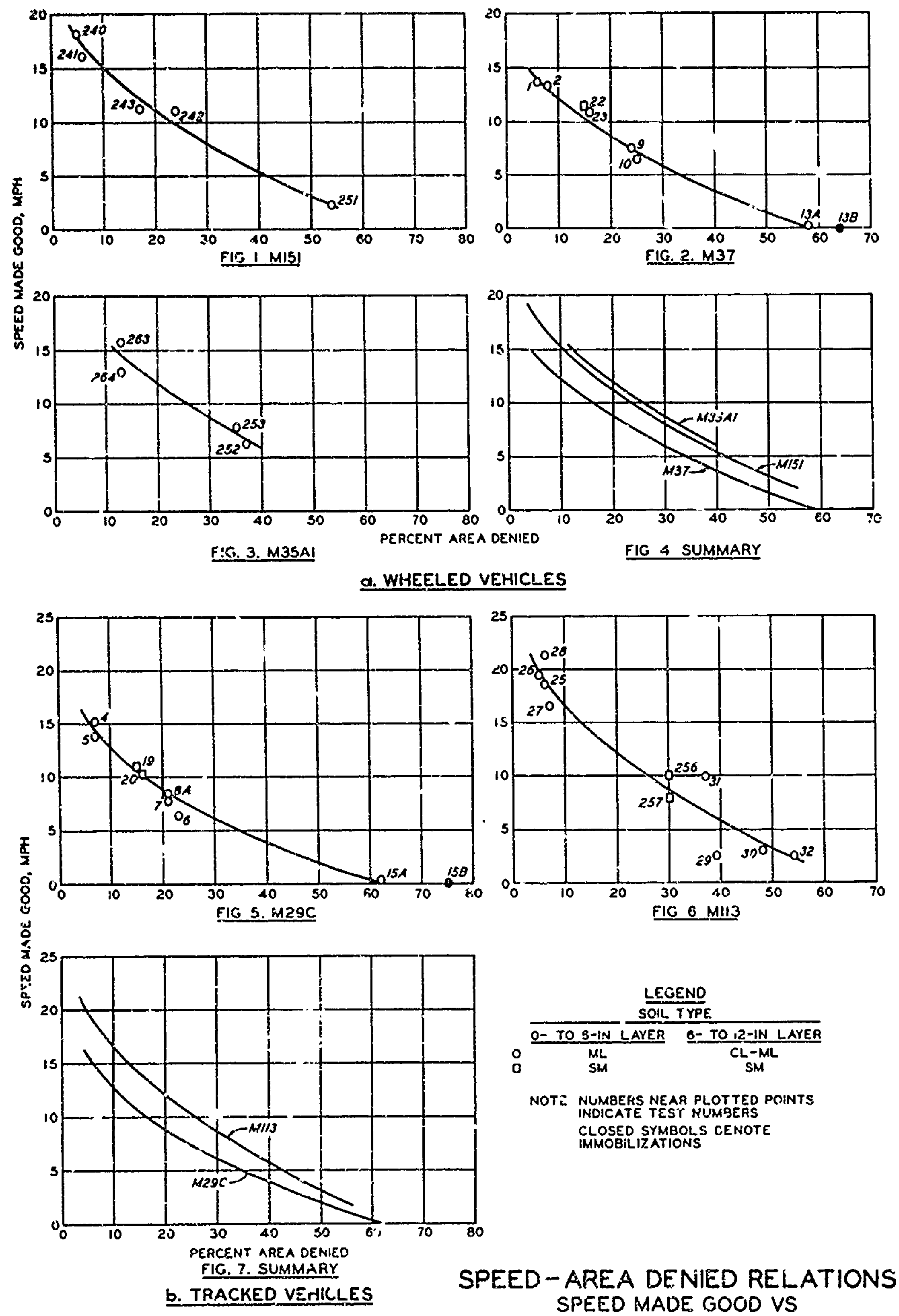
SPEED MADE GOOD VS MEAN OBSTACLE SPACING

TESTS IN COARSE-GRAINED SOILS SLOPING SURFACES



MINIMUM SPACING REQUIRED = 1.4 × VEHICLE WIDTH

MINIMUM OBSTACLE SPACING REQUIRED



SPEED-AREA DENIED RELATIONS

SPEED MADE GOOD VS
PERCENT AREA DENIED

TESTS ON FINE-GRAINED SOILS AND SANDS WITH FINES, POORLY DRAINED
NEARLY LEVEL SURFACES

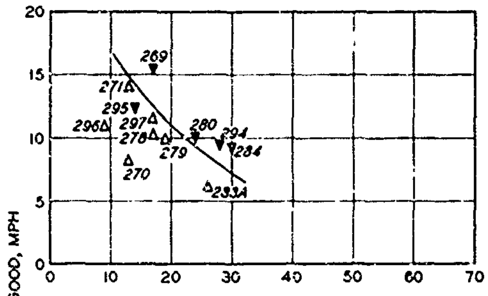


FIG. 1. M151

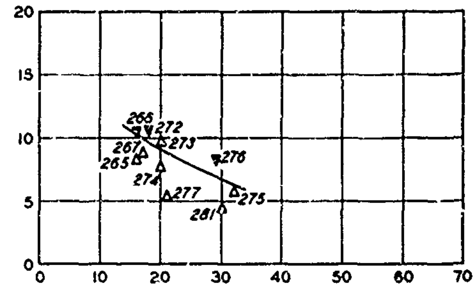


FIG. 2. M37

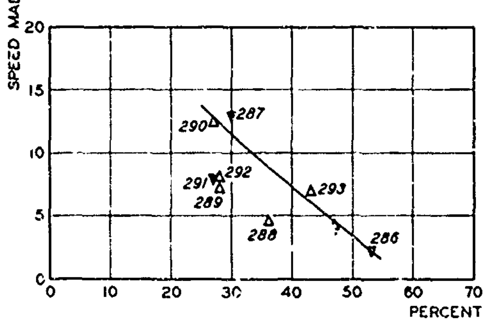


FIG 3 M35A1

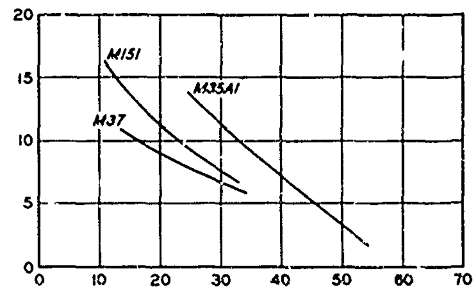


FIG 4 SUMMARY

a. WHEELED VEHICLES

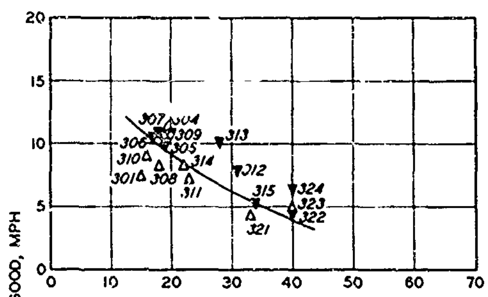


FIG 5 M29C

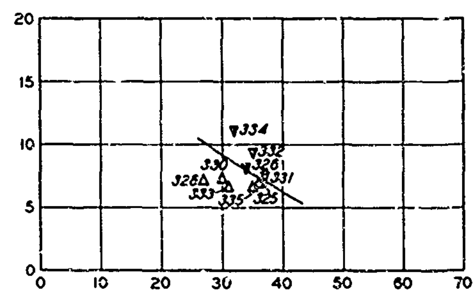


FIG 6. M113

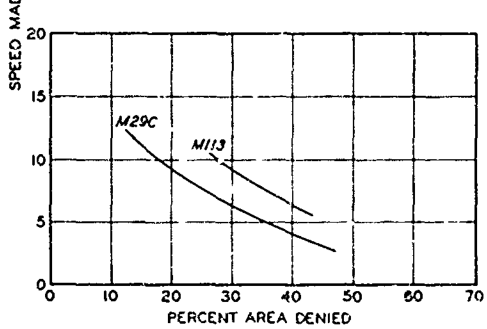


FIG 7 SUMMARY

b. TRACKED VEHICLES

LEGEND

SOIL TYPE, SP

Δ UPSLOPE

▼ DOWNSLOPE

NOTE NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBERS

SPEED-AREA DENIED RELATIONS

SPEED MADE GOOD VS PERCENT AREA DENIED

TESTS ON COARSE-GRAINED SOILS SLOPING SURFACES

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Advanced Research Projects Agency and Directorate of Development and Engineering, U. S. Army Materiel Command

13. ABSTRACT

A total of 95 lateral obstacle tests were conducted with two tracked and three wheeled vehicles at the NASA Marshall Space Flight Center, Miss., and Eglin Air Force Base, Fla. The principal conclusions from these tests were that (a) vehicle performance in terms of speed made good in an array of vegetation assemblages can be correlated with the density of vegetation assemblages expressed as mean obstacle spacing, (b) the minimum obstacle spacing required to permit movement of a vehicle can be computed from vehicle width, and (c) the speed made good a vehicle can achieve when maneuvering in lateral obstacles is significantly affected by the slope of the terrain. Methods of determining mean obstacle spacing from structural cell diameter and percent area denied from stem diameters of trees, vehicle width, and structural cell diameter are shown. A method of determining percent area denied by logs, mounds, and other obstacles is suggested.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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Cross-country tests						
Mathematical models						
Military vehicles						
Terrain						
Vegetation						

Unclassified
Security Classification